ENERGY CONSERVATION IN THE INDUSTRIAL MINERAL SECTOR - COMMINUTION -

VOLUME 1

SUMMARY REPORT - Phase I
SUMMARY REPORT - Phase II
Pilot Plant Proposal

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MICROMEDIA

SUMMARY REPORT

TABLE OF CONTENTS

Page No.

Acknowledgements i

Summary ii-x

Recommendations xi-xiii

Introduction 1-4

Energy Consumption in the Industrial Minerals Industry 5-9a

PHASE I

Requirements 10

Methodology 11

Participating Companies 12

Industry Studies 13-144

Review of Results 145-149

Computerized Data Base 150-153

PHASE II

Requirements 154

Particle Size Analysis 155-165

On-Line Applications 166-168

Conclusions 169

PILOT PLANT PROPOSAL 170-174

REFERENCES 175

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The experience and active participation of these Companies was invaluable in compiling a realistic set of data.

It is the sincere wish of Canada Cement Lafarge Ltd. that those who took part in the study will benefit from the results.

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Mr. W.A. Gow, Director, Mineral Sciences Laboratories, CANMET;

Mr. G.W. Riley, Manager, Mineral Processing Laboratory, CANMET - the Project Leader;

Mr. E.G. Joe, Senior Industrial Liaison Officer, CANMET - the Scientific Authority;

Mr. E. Fresque, Senior Science Procurement Officer, Department of Supply and Services - the Science Procurement Manager.

Special appreciation is expressed for the excellent technical contributions by Mr. D.M. Doyle of D.M. Doyle and Associates and Mr. W.R. Ford, Consultants to the project.

SUMMARY

The department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations and to stimulate R&D, commissioned this study.

The overall objective as stated by EMR was,

> to develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

Phase I

> Plant studies to develop a data base.

Phase II

> Establishment of particle size monitoring methodology.
>
> Under this phase, a proposal for pilot plant testing was developed.

Phase III

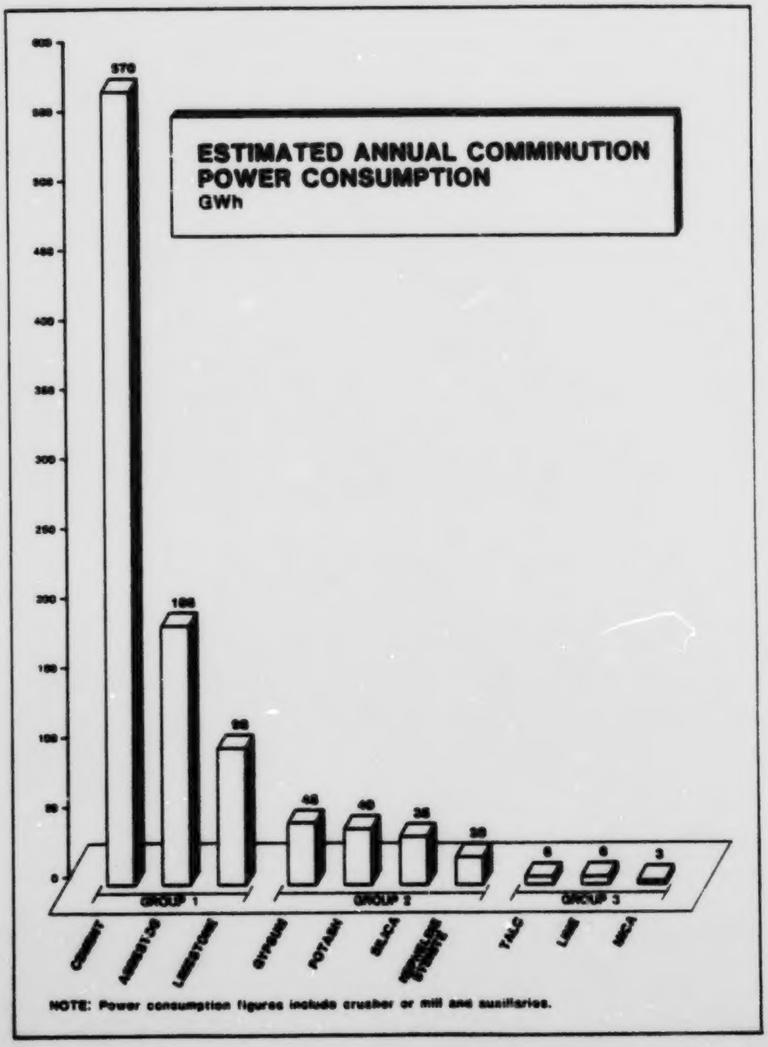
> Development of pilot plant system.
>
> Pilot plant development was not part of the scope of work.

PHASE I PLANT STUDIES TO DEVELOP A DATA BASE

RESULTS

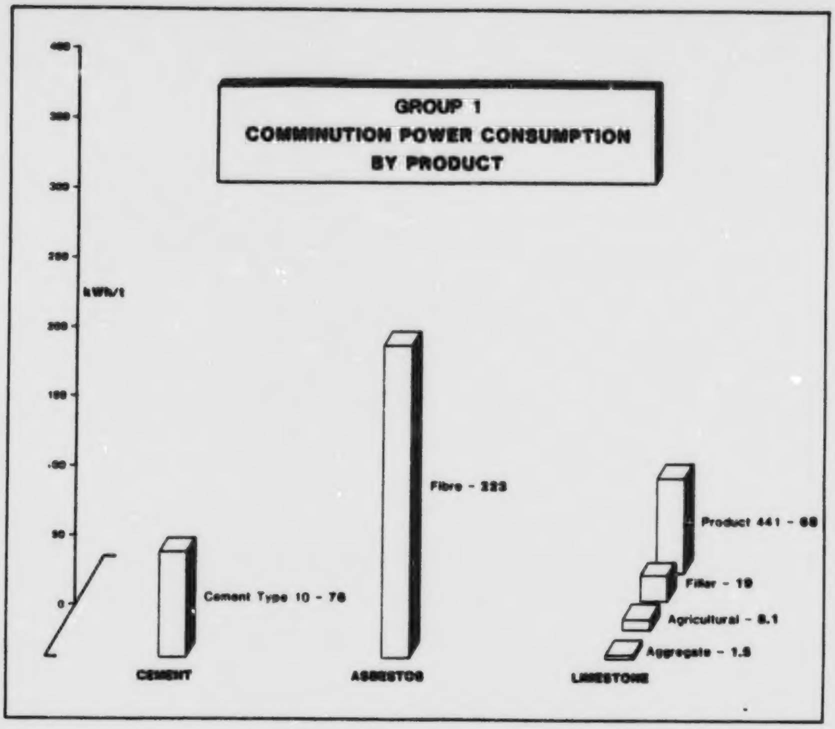
The industries can be ranked into three groups based on estimate of power consumed annually in comminution.

Group 1	Group 2	Group 3
High	Moderate	Low
Cement	Gypsum	Talc
Asbestos	Potash	Lime
Limestone	Silica	Mica
	Nepheline Syenite	



NOTE: Power consumption figures include crusher or mill and auxiliaries.

Group 1



Cement

The relatively high specific power consumption and annual tonnages over 7 million account for the high industry power demand.

In the finished product 20-25% of the particles are either too coarse or too fine to contribute to product strength. Thus, improved classification could result in considerable power conservation.

Asbestos

The asbestos industry is different from the other industrial minerals in that:

- large tonnages of ore must be processed to yield relatively small amounts of fibre,

- the role of comminution is to release fibre from the host rock rather than size reduction,
- 45% of the power consumed in comminution circuits is for dust collection.

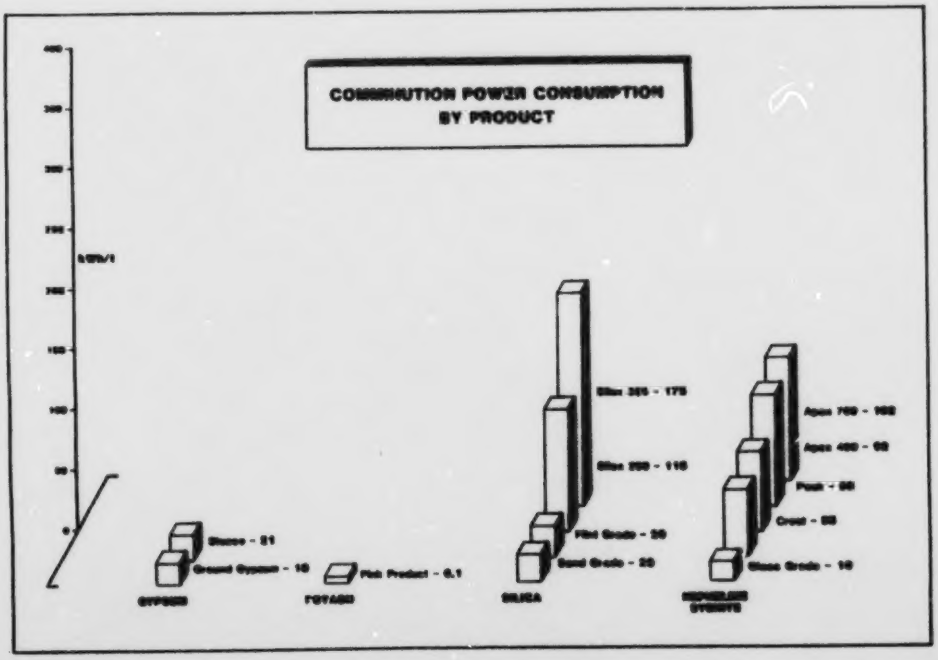
The potential for power conservation is considerable and might be achieved through wet milling.

Limestone

Industry power demand is high because close to 60 million tonnes of limestone are produced annually. Of this, however, 90% is crushed stone which requires less than 2 kWh/t.

The efficiency of the fine grinding operations, particularly at the new installations and the moderate tonnage of the fine products suggest that there is limited scope for conservation.

Group 2



Gypsum

Power consumed in comminution is relatively low compared to other industrial minerals. This can be attributable to the ease of grinding of the material and coarseness of the product.

The scope of conservation appears to be limited.

Potash

The comminution power required per tonne of product is low because there is no fine grinding. Opportunities for power conservation are limited.

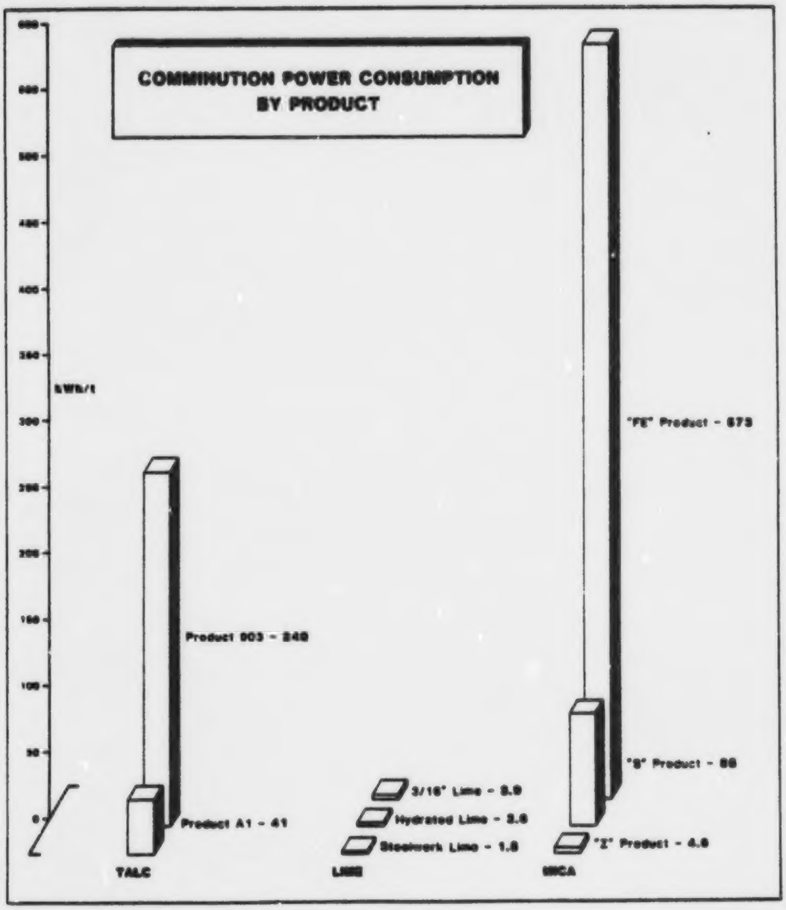
Silica

The fine products are energy intensive. Canadian sand produced from quartzite ores results in angular grains. It may be beneficial to investigate alternative grinding techniques to make round grained products to compete with imports.

Nepheline Syenite

Specific power consumption is high for finer products although these comprise a minor proportion of shipments. Energy conservation might be achieved by cutting down the number of size reduction stages in the process.

Group 3



Talc

Pulverized (95% -10 μm) product is energy intensive. Energy saving might be achieved through the use of pebble mills for grinding very fine product.

Lime

Power consumption in lime processing is low due to low grindability and coarse products. Most of consumption is for processing limestone for kiln feed. Lime itself involves minimal crushing and screening. Potential for energy conservation is low.

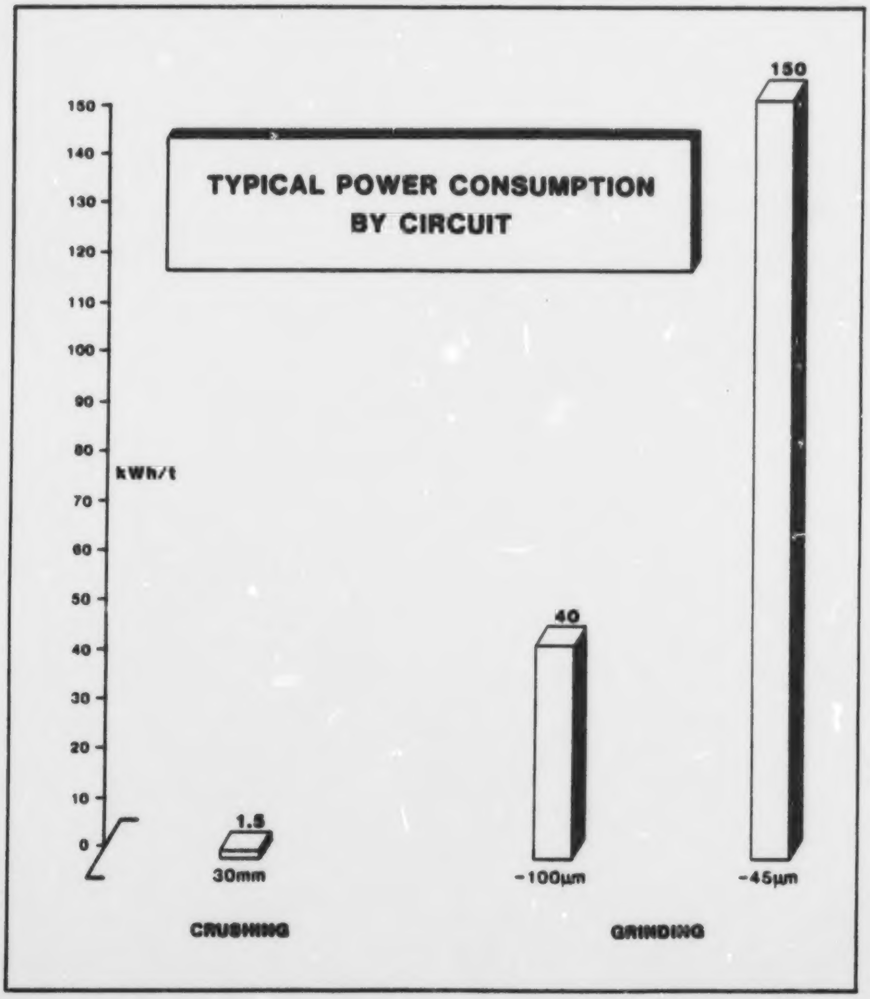
Mica

Industry power demand is low because annual production is only 11,000 tonnes.

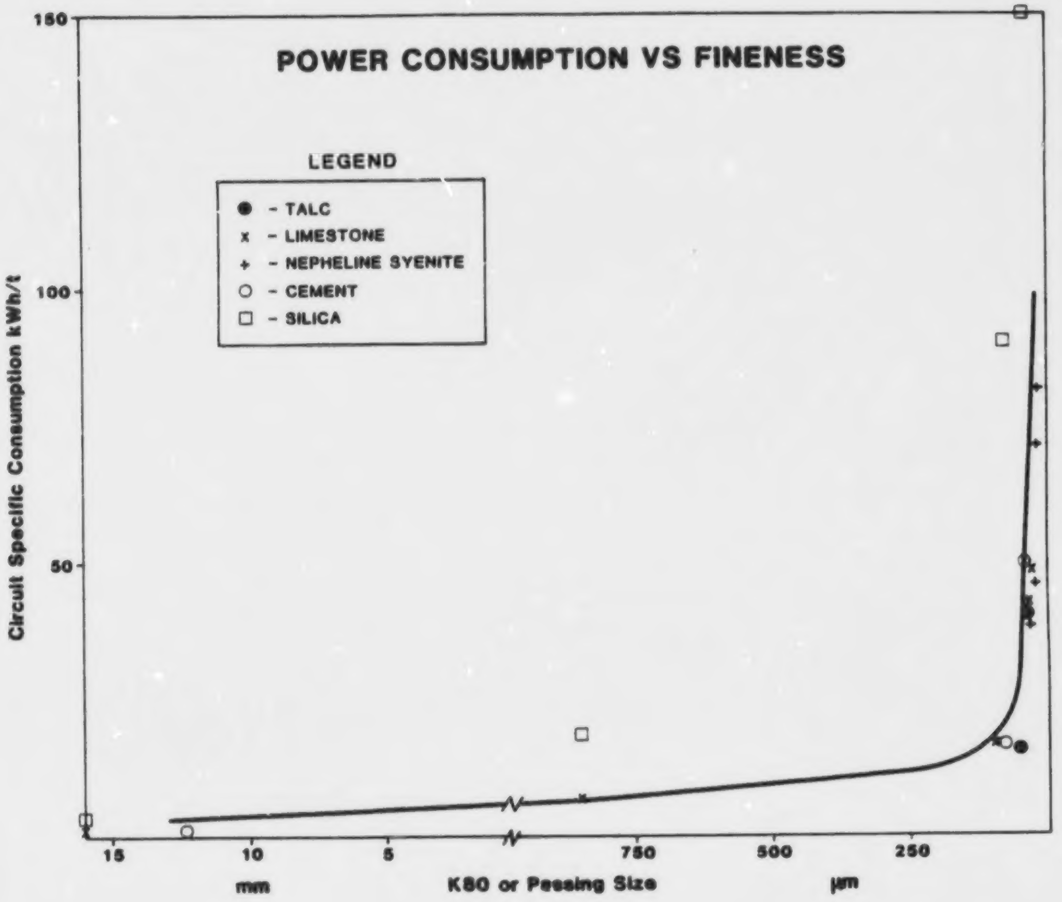
The high power consumption of the fine grinding circuit and the high abrasiveness of the mineral suggests that different milling techniques, equipment and material selection, and improved classification should be studied.

General Findings

Crushing uses considerably less power than grinding.



The power consumption in grinding increases sharply with the fineness of the product.



PHASE II ESTABLISHMENT OF PARTICLE SIZE MONITORING METHODOLOGY

RESULTS

A review of the available on-line particle size monitoring instruments indicated that further testing is needed before any can be regarded as satisfactory for use in industrial mineral processing.

The most developed systems are those based on light scattering. Of these, the Microtrac marketed by Leeds and Northrup is the most widely commercialized in North America.

The Microtrac can be used on wet or dry samples, although there are problems in ensuring dispersion of the particles in dry suspensions.

The instrument can scan the samples rapidly (25 seconds) and can cover a wide range of particle sizes (200 - 2 µm).

Comparison of the Microtrac with a Sedigraph, a laboratory instrument which measures particle sizes by sedimentation rates, indicated that for cement, the reproducibility of results of the two instruments is similar, but Microtrac readings for a given particle size tend to be higher than the Sedigraph.

The Microtrac results for the other industrial minerals were within the ±5% accuracy reported by the manufacturer.

A number of Microtrac units have been installed on-line in cement plants, but difficulties in presenting a suitably dispersed sample to the laser remain to be solved.

Automatic Blaine meters, which give a measure of specific surface area rather than a particle size distribution, are in operation in at least two cement plants for control of finish mills. The one installed in 1982 is apparently working satisfactorily. The other has just been commissioned.

RECOMMENDATIONS

We recommend that immediate action be taken to optimize comminution in the industrial mineral sector, so that the Canadian industry be in a strong position to compete with imports, to develop export markets and also be poised to take advantage of opportunities to supply fillers to the expanding plastics industry.

PHASE I

Specific Recommendations

Asbestos

Develop wet milling technology in order to reduce the power consumed in dust collection in dry milling.

Cement

Improve the classification of cement to reduce the amount of coarse and superfine material in the finished product. This represents an opportunity for Canadian manufacturers to develop new equipment or find ways of retrofitting existing classifiers.

Test the efficiency of other dry milling systems, for example, tower mills, for grinding clinker.

Mica

Test alternative milling systems for delaminating and grinding mica with a view to reduction of the power consumed in the manufacture of fine mica products with suitable aspect ratios.

Nepheline Syenite

Test the efficiency of autogenous milling to reduce the number of comminution stages.

Silica

Explore ways, for example use of attrition mills, to produce a ground silica with rounded grains suitable for foundry use to replace imports.

Talc

Investigate the use of pebble mills as a more efficient means of grinding superfine products.

General Recommendations

Investigate the action of grinding aids in preventing reagglomeration of particles in mill circuits. The investigation should involve research into the bonding forces between particles as well as pilot plant testing of commercial grinding aids.

Since crushing requires less power than milling, seek ways to optimize size reduction of mill feed in the crushing circuit.

Continue development of comminution circuit modeling to support development of mill control strategies.

Ensure transfer of information and technology to the industrial mineral industry by seminars and other means.

PHASE II

Investigate ways of dispersing and presenting dry samples to the Microtrac or other laser particle size analysers.

Test the performance of laser equipment under pilot plant conditions.

Test the performance of automatic Blaine meters.

Evaluate alternative ways of monitoring particle size, for example, using brightness.

Develop mill circuit control strategies using on-line particle size monitors.

PILOT PLANT PROPOSAL

It is proposed that, instead of constructing a new pilot plant, existing facilities be used to conduct a testing program which integrates the recommendations of this study with those of the survey made in 1982 by the Department of Energy, Mines and Resources into the problems and opportunities of the Canadian industrial minerals industry.

INTRODUCTION

The Canadian Industry Program for Energy Conservation (CIPEC) reported a 15% reduction in energy consumption per tonne of output in 1982, compared to the base year 1974. Much of this saving could be attributed to improved housekeeping. Achieving further conservation would require process modification and fuel switching; both require R&D. The areas for work were grouped as follows:

general R&D - applicable to industrial mineral processing in general,

cement R&D - processing of Portland and other hydraulic cements and gypsum plaster,

clay products R&D - applicable to manufacture of brick, tile, pipe, etc.

The department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations, commissioned this study.

The overall objective as stated by EMR was,

> to develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

EMR defined direct and indirect energy consumption in the following way.

> Direct energy consumption measures the work done during the crushing and grinding operations and is expressed in kWh/tonne.

The indirect energy consumption is less frequently recognized and harder to quantify. Its effects are felt during secondary processing or utilization of comminuted materials. The correct size distribution of cement for example could command savings of up to 10% of the amount of cement necessary to make concrete. Optimization of comminution both in terms of kWh/tonne and in terms of processing energy consumption would make a major contribution to energy conservation in the industrial minerals processing sector.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

Phase I

Plant studies to develop a data base. For each mineral, studies were made of power consumption during comminution at a plant whose operations are typical of the industry. The results are from a brief investigation of the company's operations and therefore, are descriptive rather than analytical.

Phase II

Establishment of monitoring methodology. An evaluation was made of commercially available particle size measuring equipment with a view to establishing the feasibility of mill circuit control by on-line particle size measurements.

Also under this phase, a proposal for a pilot plant test program was developed.

Phase III

Development of pilot plant system. Pilot plant development was not part of the scope of work.

Report Structure

The results of the study are presented at several different levels of detail.

- A summary report which contains the results of phase I and II and also the pilot plant proposal. The objective of this report is to give a general understanding of each of the industries which were studied, and a clear picture of the results without excessive detail.

  A typical print-out of the computerized data base is also included.

- Supporting volumes which contain for each industry, elaborate accounts of the in-plant testing programs, more detailed results, and some background information on the structure of the industry.

  Included also, is an expanded report on Phase II.

- Working papers which are available for consultation. These papers contain complete results of laboratory tests, recording charts and calculations.

In preparing these reports, care has been taken not to include information which could affect the competitive position of the cooperating companies. For this reason, some details which might be of interest to the reader have been specifically withheld.

The report does not give descriptions of the various types of crushing and grinding equipment because this has been done in numerous texts and reviews (for example, the report by SNC, Study on Energy Conservation in the Industrial Minerals Processing Sector Comminution Crushing and Grinding, Contract No. 18SQ 23440-1-9094).

The 1983 report on the Canadian Industry Program for Energy Conservation (CIPEC) gave a breakdown of energy use by the various industrial sectors. The emphasis of the report was on conservation achieved in 1982 when, despite the constraining effects of the recession, the member companies of CIPEC improved their energy efficiency by an average of 15.4%. The complete fiqures for 1983 are not yet available, but an overall improvement of 22% over the base year has been reported.

1982 Energy Use and Energy "Savings"* (Joules x 10^{15})

	1982 Energy Use	1982 Energy "Savings"
Chemicals	306.43	88.67
Electrical & Electronics	8.72	3.22
Farm & Industrial Equipment	n/a	n/a
Ferrous Metals	246.40	7.46
Food & Beverage	40.29	9.25
General Manufacturing	7.88	.28
Industrial Minerals	84.23	11.37
Machinery	1.34	.11
Mining & Metallurgy	101.50	7.41
Non-Prescription Medicine	.57	.38
Petroleum Refining	286.03	64.81
Plastics	1.35	.25
Pulp & Paper	299.70	61.40
Textiles	11.72	2.86
Transportation (Mfg.)	33.60	1.29
Wood Products (Western)	5.91	2.31
Total	1,435.67	261.07

* Additional energy that would have been used in 1982 without the efficiency improvements made since the base year.

Source: CIPEC

Industrial minerals is one of the top six energy using sectors, whose combined consumption is 92% of the industry total.

Sector	% of Total Industrial Energy Use
1) chemicals	21.3
2) pulp and paper	20.9
3) petroleum refining	19.9
4) ferrous metals	17.2
5) mining and metallurgy	7.1
6) industrial minerals	5.8
other sectors	7.8

Energy consumption by source for each of the sectors, is shown in the table below.

1982 Task Force Energy Consumption

	Purchased Fuel Consumption (% of Total)					
	Natural Gas	Liquid Petroleum	Electric Power[1]	Coal & Coke	Propane LPG	Other Fuels[2]
Chemicals	62.4	16.6	17.0	nil	nil	4.0
Electrical & Electronics	56.9	7.3	33.8	nil	nil	0.8
Farm & Industrial Equipment	n/a	n/a	n/a	n/a	n/a	n/a
Ferrous Metals	19.3	8.6	6.9	65.2	nil	nil
Food & Beverage	65.8	19.3	14.5	nil	0.4	nil
General Mfg.	52.2	19.6	27.7	nil	0.5	nil
Industrial Minerals	42.4	15.3	13.6	28.8	nil	nil
Machinery	49.8	10.6	37.2	1.5	0.8	nil
Mining & Metallurgy	17.1	31.5	43.8	5.2	2.3	nil
Non-Prescription Medicine	74.8	0.3	24.9	nil	nil	
Petroleum Refining	13.1	19.4	4.2	14.9	1.9	46.4
Plastics	54.1	1.3	43.3	nil	1.3	nil
Pulp & Paper	25.7	37.9	31.9	3.3	0.2	0.9
Textiles	26.5	46.6	23.3	nil	3.6	nil
Transportation (Manufacturing)	53.0	10.1	27.0	9.5	0.4	nil
Wood Products (Western)	55.5	nil	44.5	nil	nil	nil
Total of All Task Forces	29.5%	22.1%	18.7%	18.0%	0.7%	11.0%

[1] The Chemicals and Petroleum Refining sectors report their electric power use at the higher "gross" energy content levels. For purpose of CIPEC industry-wide compilations, these have been converted to the "standard" 3.6×10^6 J/kWh used by the other task forces. Thus the data in CIPEC displays will not compare directly with those presented in the Chemicals and Petroleum Refining Task Force reports.

[2] Other Fuels include by-products and waste, purchased steam, refinery gas and miscellaneous fuels, but exclude wood wastes, though these continue to be a major energy source for the forest products and pulp and paper sectors.

Source: CIPEC

Within the industrial minerals group, the cement and glass subsectors account for 74% of the sector's energy consumption.

Industrial Minerals Industry
Reported Data 1982

Subsector	1982 Total Energy Joules x 10^{15}	% of Total
Abrasives	1.865	2.2
Asbestos	7.290	8.7
Cement	42.569	51.8
Clay Brick	3.544	4.2
Concrete Products	0.350	0.5
Glass	19.332	22.9
Lime	7.382	8.8
Miscellaneous	1.051	1.3
Refractories	0.846	0.9
Totals	84.229	100.0

Source: CIPEC

Fuel represents 86% of the sector's energy demand.

Industrial Minerals Industry
Energy Use 1982

Subsector	Fuel		Electricity		Total
	Joules x 10^{15}	%	Joules x 10^{15}	%	J x 10^{15}
Cement	38.8	91.1	3.8	8.9	42.6
Glass	14.7	76.2	4.6	23.8	19.3
Other	19.2	86.1	3.1	13.9	22.3
Total	72.7	86.3	11.5	13.6	84.2

Source: CIPEC

Power used in Comminution

It is not possible from published data to isolate power used in comminution from total power demand in the industrial minerals sector.

However, in the case of cement, more than 50% of power demand is attributable to comminution, based on the following breakdown:

Typical Cement Power Use

	kWh/t	%
Comminution	76	54
Other	64	46
Total	140	100

In a number of the other industrial minerals, particularly those with finely ground filler products, comminution will account for a considerably greater proportion of power consumption.

Power Costs

Industrial minerals are not defined as a sector in the Standard Industrial Classification (SIC) codes and therefore are not reported on as a unit by Statistics Canada.

The minerals are classed by the SIC as follows:

Code		Industry
06		Mining
	062	Non-Metal Mines
08		Quarry & Sand Pit Industries
	081	Stone Quarries
	082	Sand & Gravel Pits
35		Ncn-Metallic Mineral Products
	352	Hydraulic Cement Industry
	356	Glass and Glass Products Industry
	358	Lime Industry
	359	Other Non-Metallic Mineral Products Industries

The published information on these groups allows partial comparison of cost of electricity compared to fuel. The data is summarized in the table below.

Consumption of Purchased Fuel and Electricity 1980 ($000)

	Fuel	Electricity	% Electricity
Mining Industry			
Metal Mines	$ 220,052	$ 174,837	45
Non-Metal Mines			
Asbestos Mines	39,340	13,537	26
Gypsum Mines	1,605	1,134	41
Potash Mines	35,260	19,415	35
Other	18,451	5,715	25
Total	96,238	40,366	29
Quarries & Sand Pits			
Stone Quarries	8,437	5,957	43
Sand Pits & Quarries	7,998	2,012	20
Total	16,434	7,970	33
Total Mines, Quarries & Oil Wells	365,305	341,100	48
Manufacturing Industry			
Non-Metallic Mineral Products			
Cement Manufacture	103,364	32,789	24
Glass & Glass Products Manufacture	37,155	13,021	26
Lime Manufacture	35,220	3,231	8
Misc. Non-Metallic Mineral Products	33,963	17,593	35
Total Non-Metallic	271,483	102,765	28
Total Manufacturing	$2,689,664	$1,759,195	40

Source: StatsCan

In the non-metal mines and non-metallic mineral products groups, power represents an average of 29 and 28%, respectively, of total energy cost.

The industrial minerals sector is not as large an energy consumer as ferrous metals or mining and metallurgy. The comparative figures for 1982 are:

	Joules x 10^{15}
- ferrous metals	246.4
- mining and metallurgy	101.5
- industrial minerals	84.2

However, the energy used in comminution per tonne processed in the industrial minerals sector is considerably greater than that in metallic mineral processing. The table below summarizes power consumption in crushing and grinding of a number of metallic ores.

Energy Consumed in Comminution in Metallic Mineral Processing

Ranges kWh/t

Metallic Ore	Crushing	Grinding
Iron	0.9 - 5.4	2.7 - 27.3
Copper	0.1 - 7.1	6.7 - 25.1
Nickel-Copper	2.4 - 13.5	9.6 - 15.8
Copper-Lead-Zinc	1.0 - 11.2	10.7 - 19.3
Lead-Zinc	1.4 - 5.5	12.7 - 15.7
Molybdenum	1.0 - 6.8	8.4 - 10.3
Gold and Silver	1.6 - 9.0	13.5 - 111.1
Uranium	5.1 - 5.5	10.5 - 13.7

Source: E.G. Joe, CIM Bulletin, June 1979.

Energy used in crushing is similar for the metallic and industrial minerals, but with the exception of gold and silver ores, grinding energy consumption ranges between 2.7 and 27.3 kWh/t for the metallic minerals. In the industrial mineral processing sector, grinding energy consumption ranges from 16.9 - 488.0 kWh/t, depending on the grindability and fineness of the product.

Since energy consumed in comminution is so significant in the industrial minerals sector, R & D action aimed at improving crushing and particularly grinding will strengthen the ability of the industry to replace imports and compete in export markets.

SUMMARY REPORT – PHASE I

PROCÉDÉ Plander ® PROCESS
MONTREAL, QUEBEC

PHASE I - REQUIREMENTS (as defined by CANMET)

Plant Studies to Develop Data Base

Studies shall be focused on the establishment of crushing/grinding characteristics and requirements for specific industrial minerals from the standpoint of both physical characteristics and energy consumption and with regard to required product specifications. The minerals of current concern include -- cement, lime, gypsum, asbestos nepheline syenite, silica, limestone, talc, mica and potash. Plant studies of typical operations for each of the noted industrial minerals shall be made. The studies shall involve compilation of data which include the following parameters:

(a) operating conditions as defined by plant management;

(b) material balance;

(c) particle characteristics and particle size distribution of various stages of crushing and grinding, of the final product(s), of the recirculating load and of any waste from by-product streams;

(d) direct energy consumption at each comminution stage;

(e) product properties as defined by specifications and user requirements;

(f) variability of all measured parameters.

The objective shall be to relate direct and indirect energy consumption to objective measurements during the various stages of crushing and grinding. These data shall be used to build mathematical models of circuit performance with respect to energy and desirable product characteristics as a basis for optimization. Data and analysis from this phase of the work shall be interfaced with the CANMET's Simulated Processing of Ore and Coal Project (SPOC). REF. MRP/MSL 80-179 (OP&J).

Each industry was studied in basically the same fashion which is outlined below:

- a background review was made to gain an understanding of the industry, its products, process and the role of comminution,
- a brief visit was made to the cooperating plant to develop with the assistance of plant personnel process flow sheets, to define the comminution circuits measurement programs, to establish product specifications and quality control methods,
- a subsequent 2-5 day visit was made to take the requisite electrical measurements, establish material flowrates and to take samples for particle size analysis and grindability testing at CCL's central laboratory,
- the data was reviewed, calculations of specific energy consumption were made for each comminution stage and comminution energy input to each product,
- an industry report was prepared and the results entered in a computerized data base.

The above methodology was suitable for measuring direct energy consumption. Because of the shortage of time with each industry, the only case of indirect energy consumption that came to our attention was in cement, where inefficient classification results in excessive coarse and superfine particles in the product.

The results obtained in this way are a "snapshot" of a plant's operation. It is assumed that the snapshot is representative of normal operations and that the plant is typical of the industry as a whole.

PARTICIPATING COMPANIES

Mineral	Company	Plant Location
Asbestos	Lac d'Amiante du Québec, Ltée	Black Lake, Quebec
Cement	Canada Cement Lafarge Ltd.	St. Constant, Quebec
Gypsum	Domtar Incorporated	Caledonia, Ontario
Lime	Domtar Incorporated *	Joliette, Quebec
Limestone	Domtar Incorporated *	Joliette, Quebec
	Steep Rock Resources Inc.	Perth, Ontario
Mica	Marietta Resources International, Ltd.	Boucherville, Quebec
Nepheline Syenite	International Minerals & Chemical Corporation	Blue Mountain, Ontario
Potash	P.C.S. Mining Ltd. Cory Division	Saskatoon, Saskatchewan
Silica	Operating plant unavailable.	
Talc	Bakertalc Incorporated	Highwater, Quebec

* Joliette plant now owned by Jolichaux Inc.

REF 434-092
PROCÉDÉ Plasdex® PROCESS
MONTRÉAL, QUÉBEC

ASBESTOS

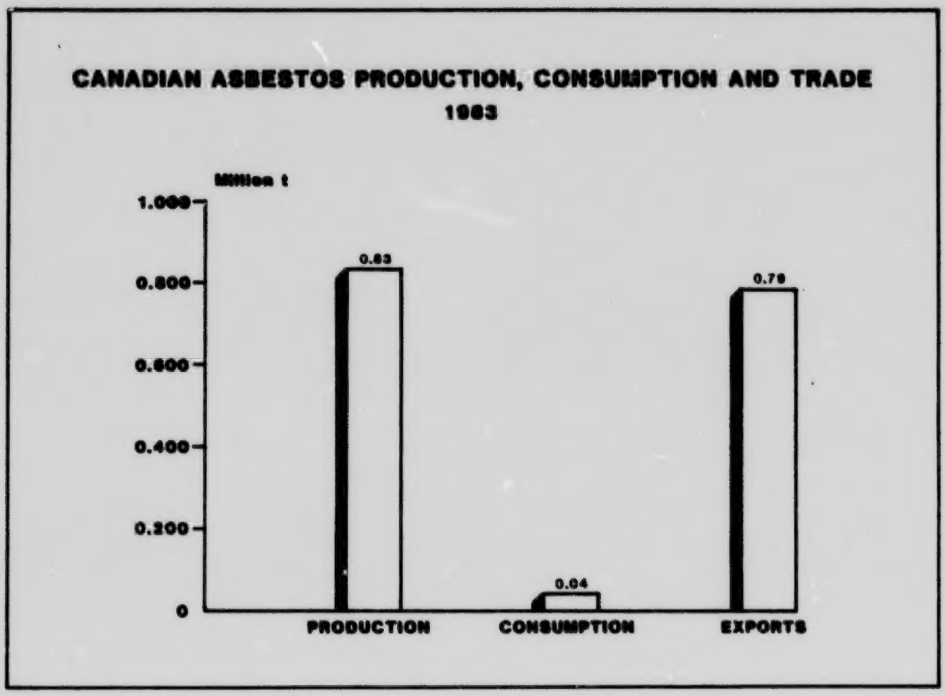
Participating Company

LAC d'AMIANTE DU QUÉBEC, LTÉE

Plant Location

Black Lake, Quebec

Asbestos: High specific power consumption - large tonnages processed, major export commodity



Source: Canadian Mining Journal, February 1984.

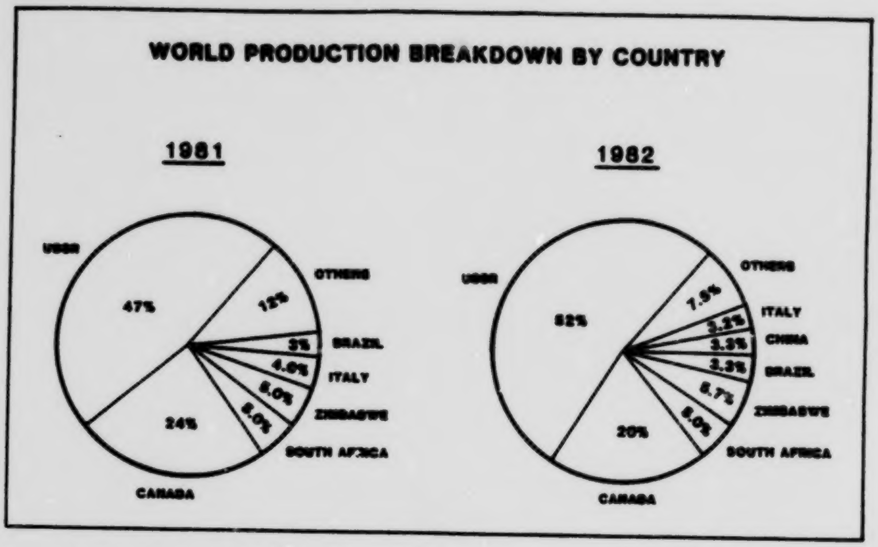
Comminution power requirement : 223 kWh/t of fiber.

Estimated comminution power requirement by the asbestos industry in 1983 : 184,600,000 kWh.

Background

Canada, with 20%, is the world's second largest producer of asbestos after the USSR, which accounts for 52% of annual production. Zimbabwe is third with 5%.

The Canadian asbestos industry is concentrated in the Eastern Townships of Quebec, smaller amounts are produced in British Columbia and Newfoundland.

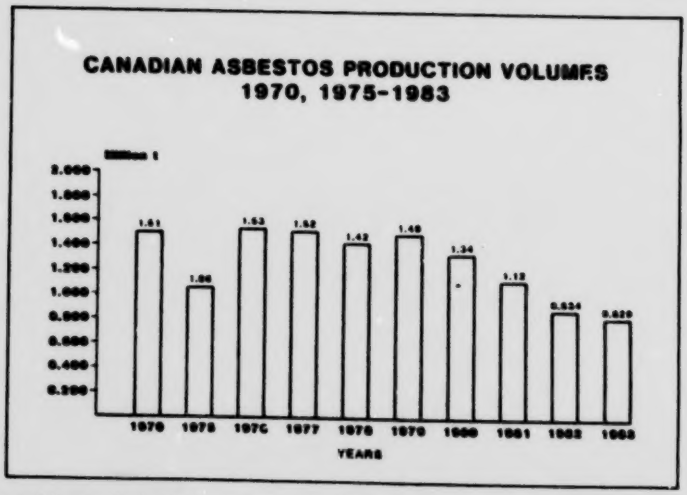

WORLD PRODUCTION BREAKDOWN BY COUNTRY

Source: Canadian Mining Journal, February 1983 & 1984.

During 1983, the production was 829,000 tonnes, with a value of $402.3 million.

Exports account for about 95 percent of Canadian production. This represents 50 percent of world export trade in asbestos.

Recessionary conditions in the construction industry, plus uncertainties regarding future environmental regulations and adverse publicity regarding exposure to dust in industry, have reduced shipments of asbestos fibre in the last few years.


CANADIAN ASBESTOS PRODUCTION VOLUMES
1970, 1975-1983

Source: Canadian Mining Journal, February 1983 & 1984.

Products and Uses

Chrysotile asbestos is the result of an alteration and metamorphosis of basic igneous rocks rich in magnesium silicate. Impurities are iron, chrome and nickel. A typical chemical composition and relevant physical properties are summarized in the tables below.

APPROXIMATE COMPOSITIONS CHRYSOTILE ASBESTOS	
Component	% By Weight
SiO_2	37-44
MgO	39-44
FeO	0-6
Fe_2O_3	0.1-5
Al_2O_3	0.2-1.5
H_2O	12-15

PHYSICAL PROPERTIES		
Specific Heat	:	1.113 J/kg.K
Specific Gravity	:	2.55 gm/cc
pH	:	9.6 - 9.75
Tensile Strength	:	552 - 689 MPa
Fusion Point	:	1520°C
Electrical Charge	:	Positive

The asbestos industry has classified and priced its products by groups from the longest and most expensive fibre to the shortest and cheapest fibre.

The major uses for chrysotile asbestos fibre are:

POSSIBLE USES OF CHRYSOTILE ASBESTOS FIBRE

Fibre Class	**Groups**	**Uses**
LONG	1 and 2 Crudes	Processed industrially into long spinning fibres used in textiles and the electrical industry.
	3 Milled	Textiles, asbestos papers, packings, brake linings, clutch facings, pipe coverings, and insulating blocks.
MEDIUM	4 Milled	Reinforcing in asbestos-cement products: pipe, shingles, jackets pipe coverings, asbestos-cement packing, gaskets, millboards, roof coatings and plastics.
	5 Milled	Asbestos-cement sheets, corrugated or flat boards, pipes, electrical panels, asbestos papers, millboards, pipe coverings, brake linings, asbestos-cements, roof coatings, putties and plastics.
	6 Milled	Asbestos-cement shingles, corrugated or flat sheets, boards, brake linings, asbestos papers, millboards, asphalt roof coatings, putties and plastics.
SHORT	7, 8, 9 Milled	Certain papers, insulating cement, asphalt roof coatings, putties, paints, welding rods, floor tiles, plastics, acoustical plaster, fibrated greases, oil well muds.

Each group is subdivided into subgroups according to the fibre's openness; that is, how finely the fibres have been distributed. "Openness" has a considerable effect on the properties of the manufactured production which the fibre is to be used.

Since there are numerous uses for asbestos fibre, processing plants must be able to ship a range of products. Quebec producers, for example, supply some 150 different classifications.

Testing programs monitor and control the flow of fibre in production and assure that finished fibre grades meet both the quality and uniformity specifications. Most tests measure properties related to fibre length distribution, degree of openness, strength unit, and filtration rate.

QAMA Standard Tests

FIBRE LENGTH
1. Quebec standard screen
2. Ro-Tap screen
3. Bauer-McNett screen
4. Suter Webb comb
5. Wash test for 200 mesh fines

FIBRE OPENNESS
1. Wet volume or buoyancy
2. Loose density or dry bulk
3. Surface area by air permeability
4. Crudy or grit content
5. Viscosity
6. Kerosene retention
7. Penetration index
8. Oil absorption

MISCELLANEOUS
1. Tensile strength
2. Asbestos-cement strength
3. Color
4. Quantitative chemical analysis
5. Moisture content
6. Magnetic rating
7. Freeness or filtration

The Production Process

Production of asbestos fibre requires mining of enormous amounts of ore, as the asbestos-dry rock ratio is about 5%. Normally, two-thirds of a day's mining production is rejected, leaving the remaining one-third to enter the processing plant.

There are four process operations, crushing, drying, milling, and grading; the first three involving comminution, as the flow sheet on page 19 shows.

The selected ore as received from the mine goes through primary and secondary crushing and then is dried in preparation for milling. The moisture content is reduced to between 1.5 and 0.5 percent. The ore is beneficiated by eliminating 45 percent of the gangue material.

The beneficiated material is milled to release the fibres from the host rock which are then graded to achieve specific product characteristics.

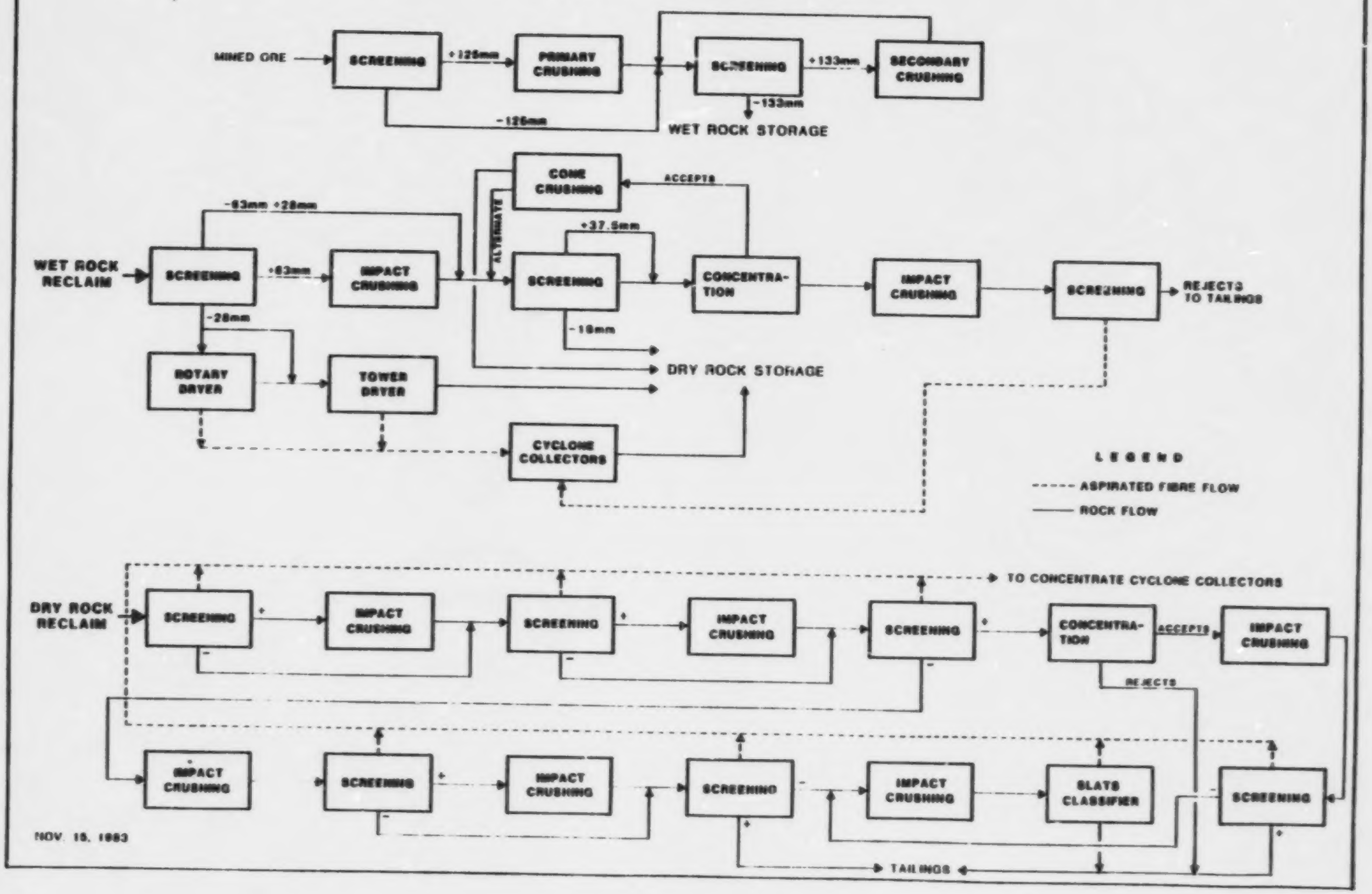
The Role of Comminution

There are three comminution steps in asbestos manufacture.

Crushing, where mined ore is reduced to a size suitable for the drying circuit.

Drying, is the ore preparation circuit. The objectives are to reduce the moisture content to acceptable levels of 1.5 to 0.5 percent and the removal of iron and other undesirable material to tailings, which approximates 45 percent of the feed. Impactors and a cone crusher are the equipment used in the circuit.

ASBESTOS
PROCESS FLOW SHEET – ROCK PROCESSING
LAC D'AMIANTE, BLACK LAKE, QUEBEC


MINED ORE
SCREENING
+125mm
PRIMARY CRUSHING
-125mm
SCREENING
+133mm
SECONDARY CRUSHING
-133mm
WET ROCK STORAGE
WET ROCK RECLAIM
SCREENING
-63mm +28mm
+63mm
IMPACT CRUSHING
-28mm
ROTARY DRYER
TOWER DRYER
CONE CRUSHING
ALTERNATE
ACCEPTS
+37.5mm
SCREENING
-19mm
CONCENTRATION
IMPACT CRUSHING
SCREENING
REJECTS TO TAILINGS
DRY ROCK STORAGE
CYCLONE COLLECTORS
LEGEND
ASPIRATED FIBRE FLOW
ROCK FLOW
DRY ROCK RECLAIM
SCREENING
+
-
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SCREENING
TO CONCENTRATE CYCLONE COLLECTORS
CONCENTRATION
ACCEPTS
IMPACT CRUSHING
REJECTS
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SLATE CLASSIFIER
SCREENING
TAILINGS

NOV. 15, 1983

Milling, is the fibre production circuit. There are several levels of milling; each involving screening, aspiration, and impacting. The purpose is to allow the fibre to be drawn off to cyclone collectors and to eliminate the host rock.

Comminution at Lac d'Amiante

The Crushing Circuit

The flow diagram with power levels in kilowatts is shown on page 21.

The **flowrate** is 750 t/h to the apron feeder.

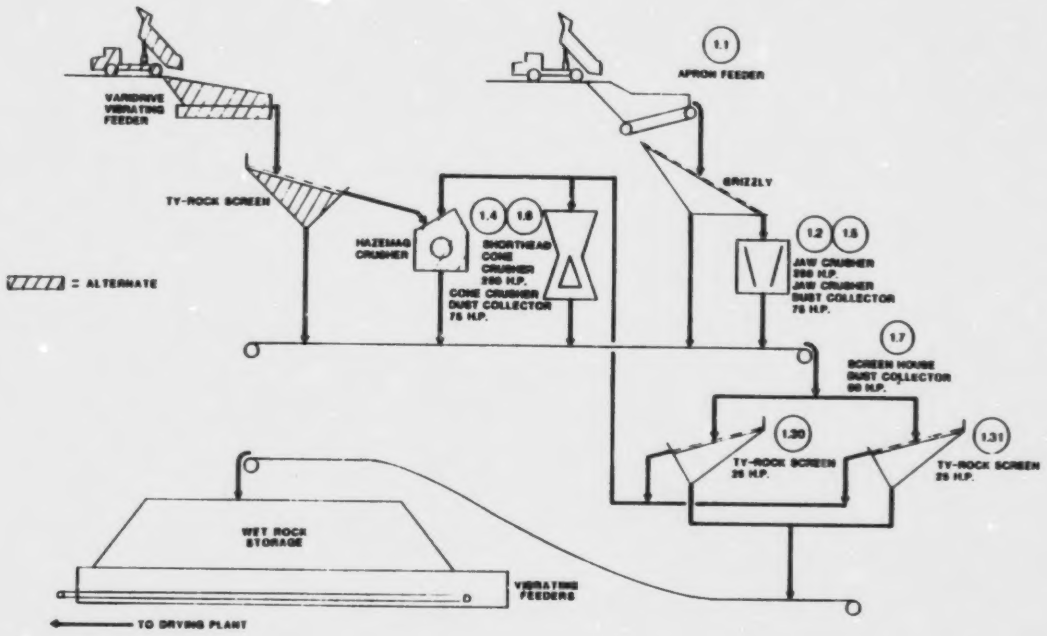
Grindability tests by the Hardgrove and Bond methods were tried but were unsuccessful because of the fibrous nature of the material.

Size distribution. No samples of the feed were taken because of the large dimensions of the rock. However, the distribution on the apron feeder ranged from 1m x 1m x 0.3m to fines. Between 30-40 percent passes directly through the 127 mm grizzly to the secondary screens together with the primary crusher discharge.

Secondary screening discharge, less than 133 mm, provides the drying circuit feed.

The Drying Circuit

The flow diagram and equipment power levels in kilowatts are shown on page 22.


1.1
APRON FEEDER
VARIDRIVE VIBRATING FEEDER
GRIZZLY
TY-ROCK SCREEN
HAZEMAG CRUSHER
1.4
1.6
SHORTHEAD CONE CRUSHER 250 H.P.
CONE CRUSHER DUST COLLECTOR 75 H.P.
1.2
1.5
JAW CRUSHER 250 H.P.
JAW CRUSHER DUST COLLECTOR 75 H.P.
= ALTERNATE
1.7
SCREEN HOUSE DUST COLLECTOR 60 H.P.
1.30
TY-ROCK SCREEN 25 H.P.
1.31
TY-ROCK SCREEN 25 H.P.
WET ROCK STORAGE
VIBRATING FEEDERS
TO DRYING PLANT

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	KW AVG.
1.1	Apron Feeder	11.1/7.5
1.2	Jaw Crusher	153
1.30	Ty-Rock Screen-F800	4.9
1.31	Ty-Rock Screen-F800	5.0
1.4	7' Shorthead Cone Crusher	136
1.5	Jaw Crusher Dust Collector	23
1.6	Cone Crusher Dust Collector	18
1.7	Screen House Dust Collector	43

CANADA CEMENT LAFARGE LTD.
MONTREAL

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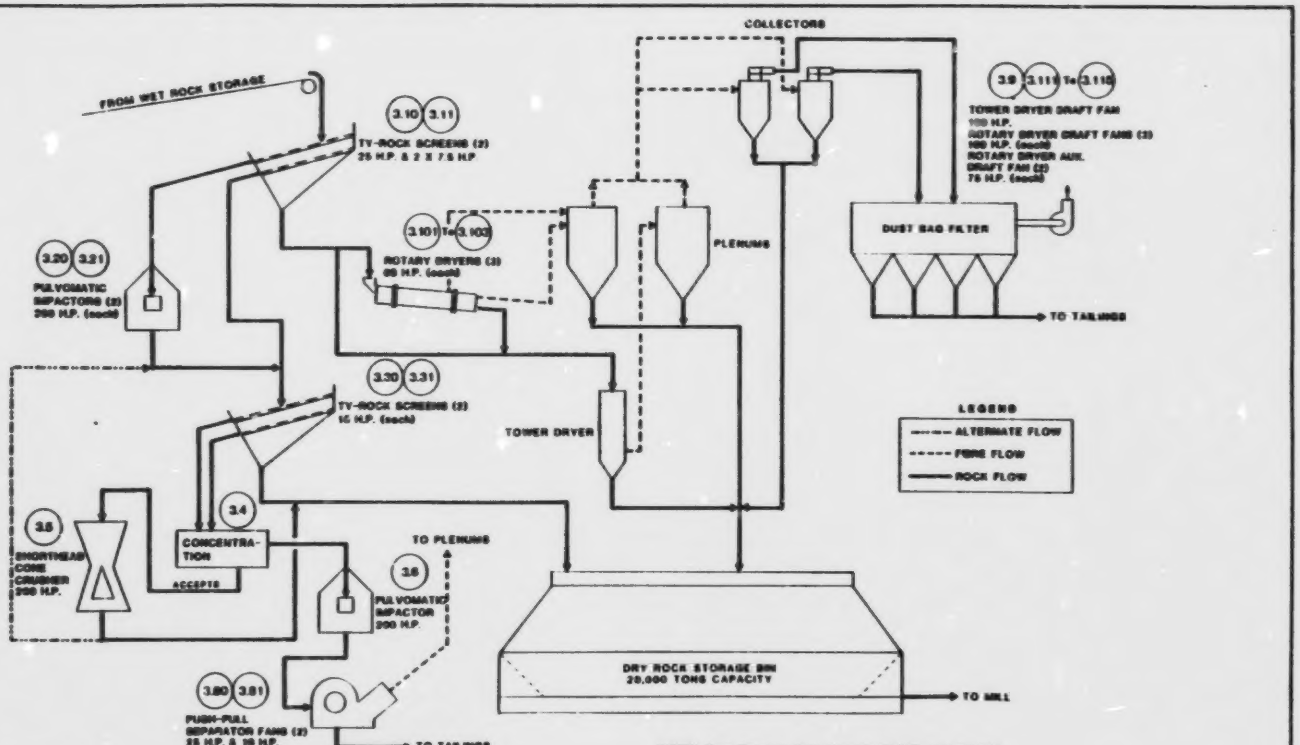
DATE 16/11/83
CHECKED DCS
DATE 20/09/84

CRUSHING CIRCUIT
FLOW DIAGRAM

PLANT AT LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010


FROM WET ROCK STORAGE
3.10
3.11
TY-ROCK SCREENS (2)
25 H.P. & 2 X 7.5 H.P.
3.20
3.21
PULVOMATIC
IMPACTORS (2)
250 H.P. (each)
3.101 To 3.103
ROTARY DRYERS (3)
60 H.P. (each)
3.30
3.31
TY-ROCK SCREENS (2)
15 H.P. (each)
TOWER DRYER
3.4
3.5
SHORTHEAD
CONE
CRUSHER
200 H.P.
CONCENTRA-
TION
ACCEPTS
TO PLENUMS
3.6
PULVOMATIC
IMPACTOR
250 H.P.
3.80
3.81
PUSH-PULL
SEPARATOR FANS (2)
25 H.P. & 10 H.P.
TO TAILINGS
COLLECTORS
PLENUMS
3.9
3.111 To 3.115
TOWER DRYER DRAFT FAN
100 H.P.
ROTARY DRYER DRAFT FANS (3)
100 H.P. (each)
ROTARY DRYER AUX.
DRAFT FAN (2)
75 H.P. (each)
DUST BAG FILTER
TO TAILINGS
LEGEND
ALTERNATE FLOW
FINE FLOW
ROCK FLOW
DRY ROCK STORAGE BIN
20,000 TONS CAPACITY
TO MILL

NOTE: Two Screens (not shown) 10 H.P. and 15 H.P.

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
3.10	Ty-Rock Screen - F600	8.6
3.11	Ty-Rock Screen - F600	2x2.6
3.20	Pulvomatic Impactor	89
3.21	Pulvomatic Impactor	90
3.30	Ty-Rock Screen - F600	4.3
3.31	Ty-Rock Screen - F600	4.4
3.4	Concentration	15.4
3.5	5-1/2' Shorthead Cone Crusher	68
3.6	Pulvomatic Impactor	103
3.70	Screen	3.4
3.71	Screen	12.8

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
3.80	Push-Pull Separator Fan	15.6
3.81	Push-Pull Separator Fan	5.2
3.9	Tower Dryer Draft Fan	72
3.101	Rotary Dryer Drive #2	-
3.102	Rotary Dryer Drive #3	47
3.103	Rotary Dryer Drive #4	33
3.111	Rotary Dryer Draft Fan #2	-
3.112	Rotary Dryer Draft Fan #3	49
3.113	Rotary Dryer Draft Fan #4	53
3.114	Auxiliary Draft Fan	44
3.115	Auxiliary Draft Fan	39

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DATE 29/08/84

DRYING CIRCUIT
FLOW DIAGRAM

PLANT nº LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010

The **flowrate** depends on the moisture content and is seasonal, being slowest in the winter. The reclaim rate from wet rock storage was 655 t/h and the beneficiated feed to dry rock storage was 344 t/h.

The objective is to condition and dry the ore. The smaller sizes, less than 28 mm, contain the moisture and require drying. The larger sizes are crushed, screened, concentrated by removing the magnetic material, crushed again and sent to dry rock storage.

The rejects are crushed again, then aspirated to recover some additional fibre, with the remainder going to tailings.

Size distribution of the feed and product from the Ty-Rock screen impactor, cone crusher and concentration impactor are summarized in the next table.

Drying Circuit Size Distribution (% Passing)

	TY-ROCK SCREEN IMPACTOR		CONE CRUSHER		CONCENTRATION IMPACTOR	
mm	Feed	Disch.	Feed	Disch.	Feed	Disch.
133	100				100	100
75		100	100		95.5	99.2
50	47.9	85.0	88.0	100	76.8	88.0
38.1			79.0	94.4		
25.0	9.2	48.9	49.7	68.1	31.3	56.4
19.0	5.2	36.7	26.0	36.7	12.2	40.4
12.5	2.9	24.7	5.7	12.7	1.9	22.3
9.5			5.3	10.2		
6.3		14.0			0.7	10.4
4.75			2.6	6.8		
2.36			2.2	4.8		
1.60						3.9

Milling

The flow diagram with the equipment power demands is shown on page 25.

During the study, the **feedrate** to the circuit was measured at 323 t/h.

Size distributions of the material flow through the system are as shown.

LAC D'AMIANTE DU QUÉBEC, LTÉE
Mill Rock Circuit
Size Distributions (% Passing)

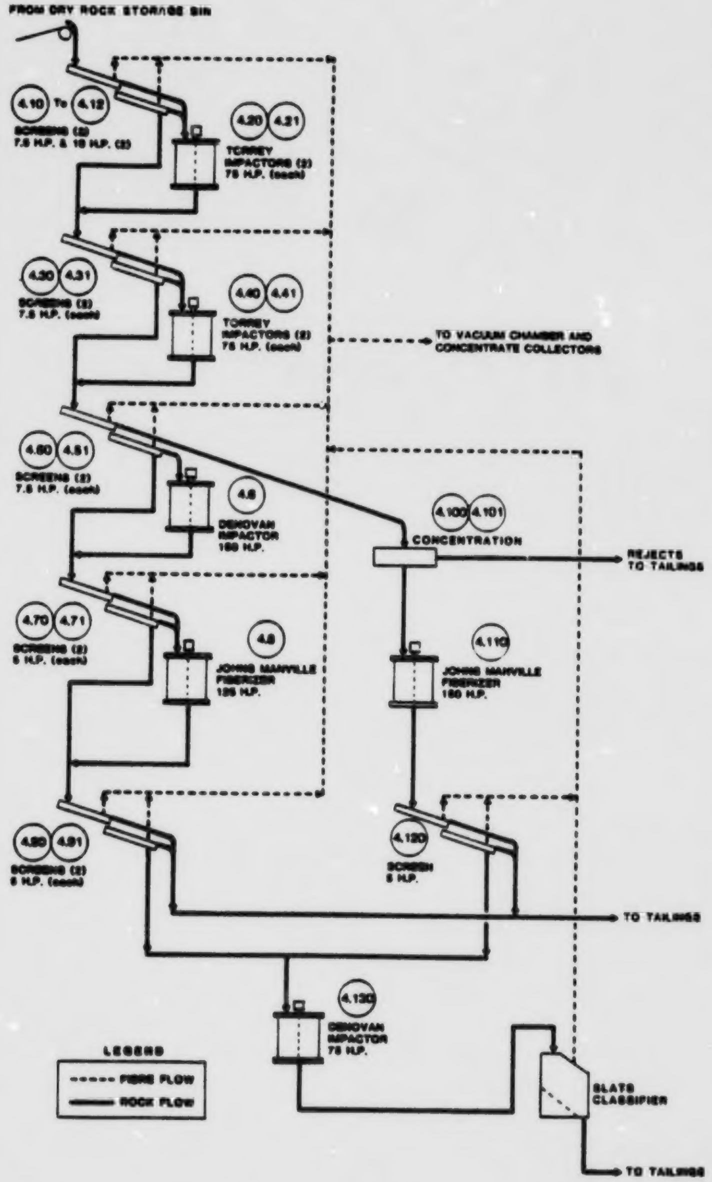
mm	TORREY (4.2)		TORREY (4.4)		DENOVAN (4.6)		J.M. FIBERIZER (4.8)	
	FEED	DISCH.	FEED	DISCH.	FEED	DISCH.	FEED	DISCH.
50	100	100	100					
38.1	99.0	99.8	99.7	100				
25.0	95.0	99.3	98.4	99.8				
19.0	88.0	96.5	95.0	99.3				
16.0	80.5	94.8	90.9	98.4				
12.5	65.4	89.6	81.8	95.1	100			
9.5	44.7	79.9	65.7	87.4		100		
6.3	23.8	64.9	47.1	74.9	53.9	73.9	100	100
2.36	6.0	39.5	18.4	43.9	28.8	40.6	57.3	84.7
1.40	3.3	25.0	6.2	24.6	11.4	16.9	13.2	57.6
1.00	2.7	17.9	3.8	17.1			7.4	39.8
0.600	2.4	13.5	2.2	12.4	4.6	7.3	3.7	28.7
0.425	1.4	9.9	1.6	9.1			3.0	21.0

Grading & Aspiration

The circuit is shown diagrammatically on the flow diagram on page 26 with the equipment power levels.

The fibre production rate was determined to be 17.85 t/h.

The aspiration system is large and significant in asbestos production. The vacuum chamber processes 336,000 m^3 per minute through 21,000 polyester bags.


FROM DRY ROCK STORAGE BIN
4.10 To 4.12
SCREENS (3)
7.5 H.P. & 10 H.P. (2)
4.20 4.21
TORREY
IMPACTORS (2)
75 H.P. (each)
4.30 4.31
SCREENS (2)
7.5 H.P. (each)
4.40 4.41
TORREY
IMPACTORS (2)
75 H.P. (each)
TO VACUUM CHAMBER AND
CONCENTRATE COLLECTORS
4.50 4.51
SCREENS (2)
7.5 H.P. (each)
4.6
DENOVAN
IMPACTOR
150 H.P.
4.100 4.101
CONCENTRATION
REJECTS
TO TAILINGS
4.70 4.71
SCREENS (2)
5 H.P. (each)
4.8
JOHNS MANVILLE
FIBERIZER
125 H.P.
4.110
JOHNS MANVILLE
FIBERIZER
150 H.P.
4.90 4.91
SCREENS (2)
5 H.P. (each)
4.120
SCREEN
5 H.P.
TO TAILINGS
4.130
DENOVAN
IMPACTOR
75 H.P.
LEGEND
----- FIBRE FLOW
——— ROCK FLOW
SLATS
CLASSIFIER
TO TAILINGS

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
4.10	Screen	1.5
4.11	Screen	4.3
4.12	Screen	4.7
4.20	Torrey Impactor	36
4.21	Torrey Impactor	36
4.30	Screen	4.5
4.31	Screen	7.0
4.40	Torrey Impactor	31
4.41	Torrey Impactor	28
4.50	Screen	4.9
4.51	Screen	3.9
4.6	Denovan Impactor	53
4.70	Screen	3.6
4.71	Screen	3.5
4.8	J-M Fiberizer	41
4.90	Screen	4.1
4.91	Screen	3.8
4.100	Concentration	2.4
4.101	Concentration	2.6
4.110	J-M Fiberizer	64
4.120	Screen	3.7
4.130	Denovan Impactor	38

CANADA CEMENT LAFARGE LTD.
MONTREAL

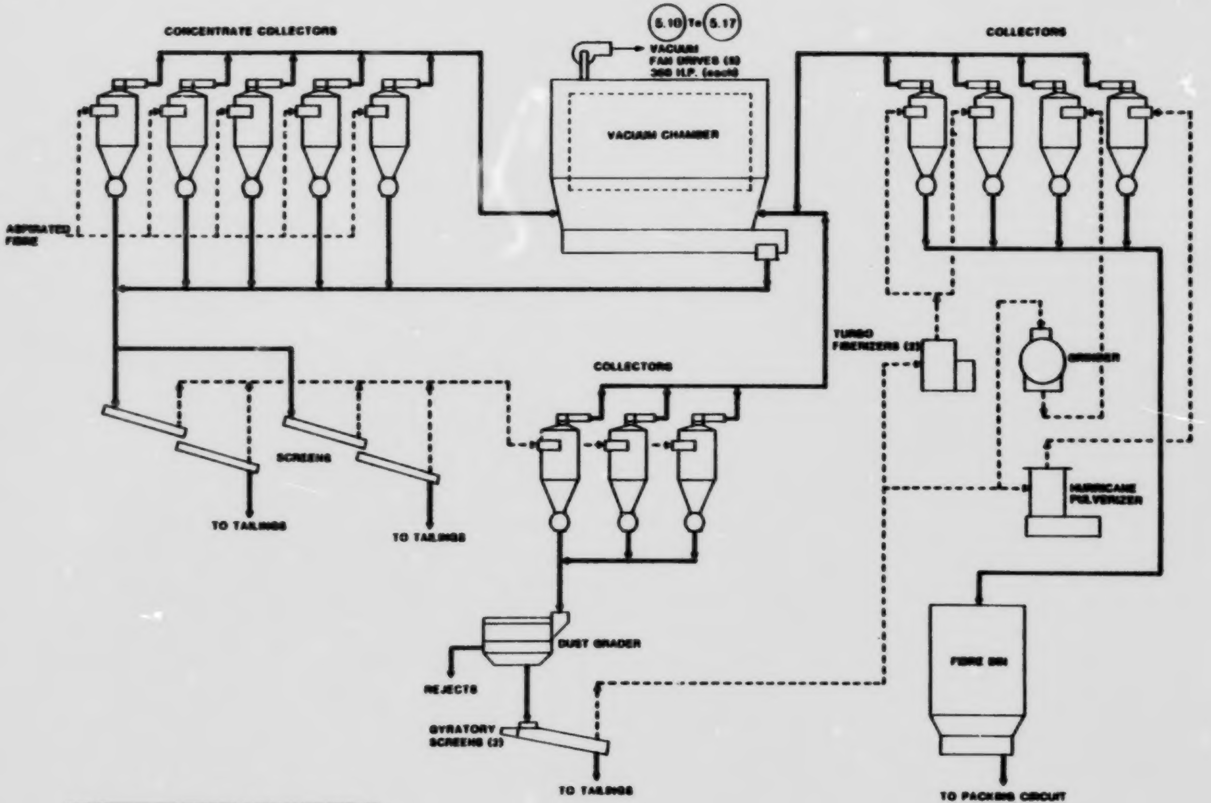
MILLING CIRCUIT
FLOW DIAGRAM

PLANT AT LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010

DRAWN GFJ
DATE 18/11/83

CHECKED DCS
DATE 20/09/84


CONCENTRATE COLLECTORS
5.10 To 5.17
VACUUM FAN DRIVES (8) 300 H.P. (each)
COLLECTORS
VACUUM CHAMBER
ASPIRATED FIBRE
TURBO FIBERIZERS (2)
GRINDER
COLLECTORS
SCREENS
TO TAILINGS
TO TAILINGS
HURRICANE PULVERIZER
DUST GRADER
REJECTS
GYRATORY SCREENS (2)
TO TAILINGS
FIBRE BIN
TO PACKING CIRCUIT

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
5.10	Vacuum Fan Drive #1	217
5.11	Vacuum Fan Drive #2	223
5.12	Vacuum Fan Drive #3	239
5.13	Vacuum Fan Drive #4	226
5.14	Vacuum Fan Drive #5	219
5.15	Vacuum Fan Drive #6	226
5.16	Vacuum Fan Drive #7	209
5.17	Vacuum Fan Drive #8	247

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 16/11/83
CHECKED DCS
DATE 20/09/84

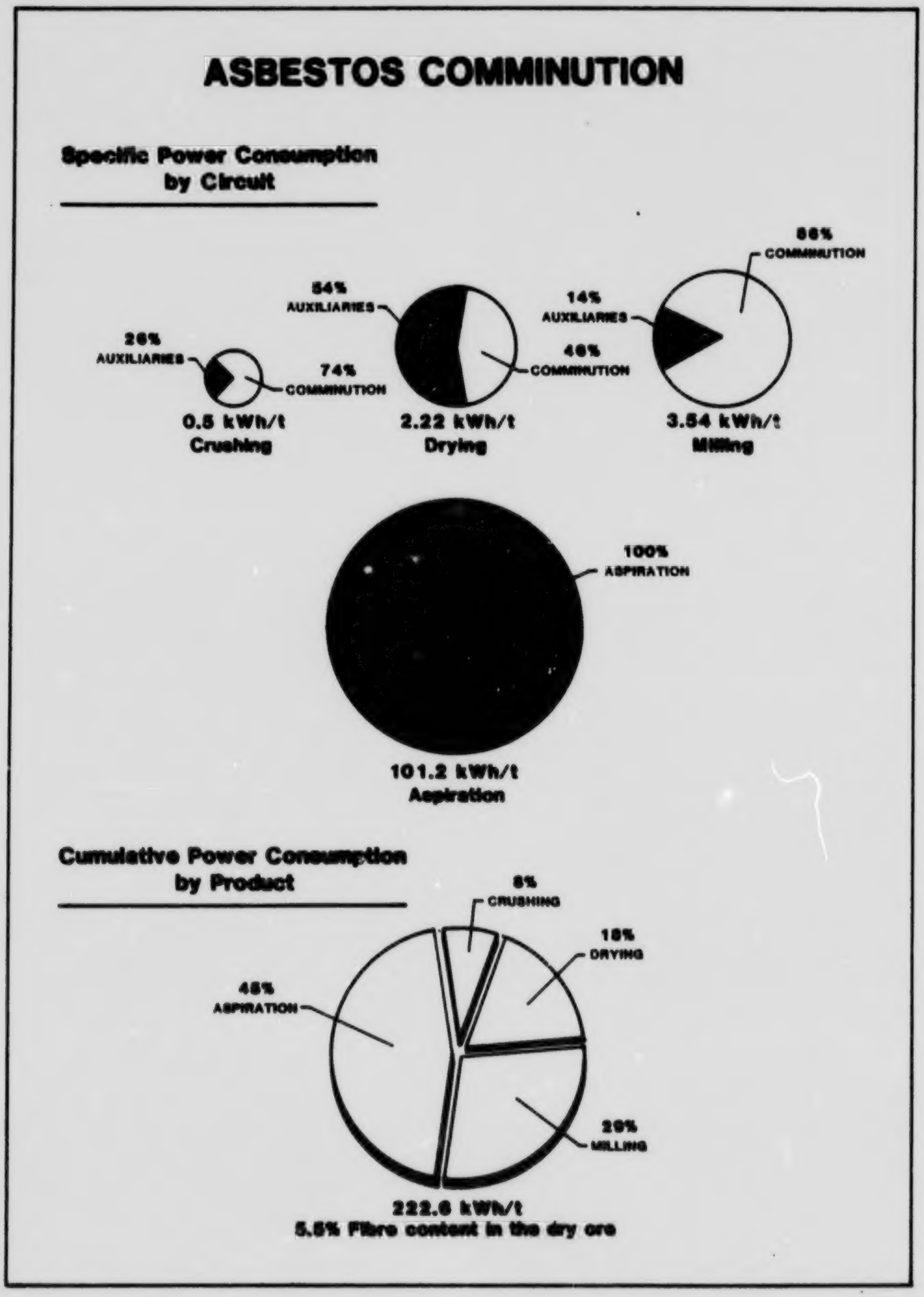
ASPIRATION AND GRADING CIRCUIT
FLOW DIAGRAM

PLANT of LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010

Results

The specific power consumption in the crushing, drying and milling circuits are summarized below.



Conclusions

From the study, it can be concluded that:

- the results are considered as a fair representation of the power consumption for comminution by the industry;
- the air handling system is a significant energy consumer;
- the fibre to dry rock ratio of 5.53 percent requires the mining of large quantities of ore to achieve required production rates;
- many comminution stages are required to continuously release the fibre from the host rock.

Recommendations

Due to the stringent dust control requirements and the present high energy consumption of the air handling system, the use of wet grinding should be investigated.

CEMENT

REF 134 [illegible]
PROCEDE Plasdex ® PROCESS
MONTREAL QUEBEC

CEMENT

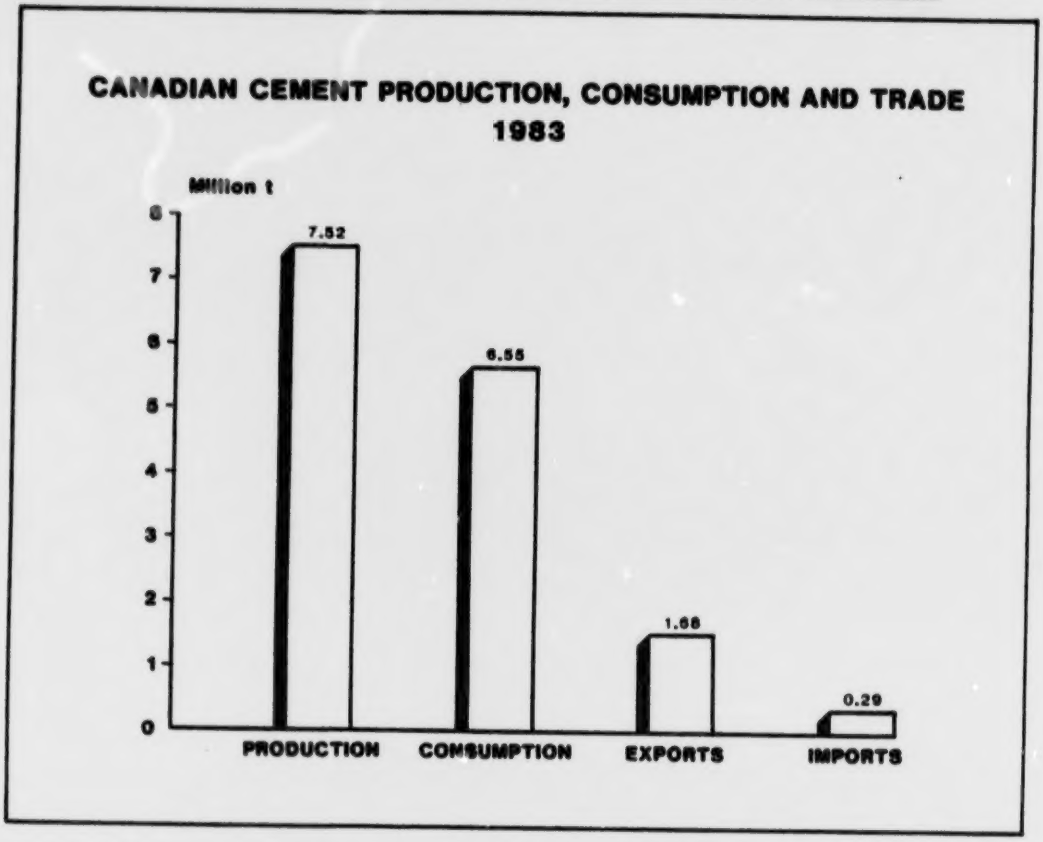
Participating Company

CANADA CEMENT LAFARGE LTD.

Plant Studied

St. Constant, Quebec

Cement: High Specific Power Consumption - High Tonnages



Source: The North American Cement Review, March 1984, Douglas M. Queen, Inc.

Comminution power requirement - Type 10 cement : 76.0 kWh/t.

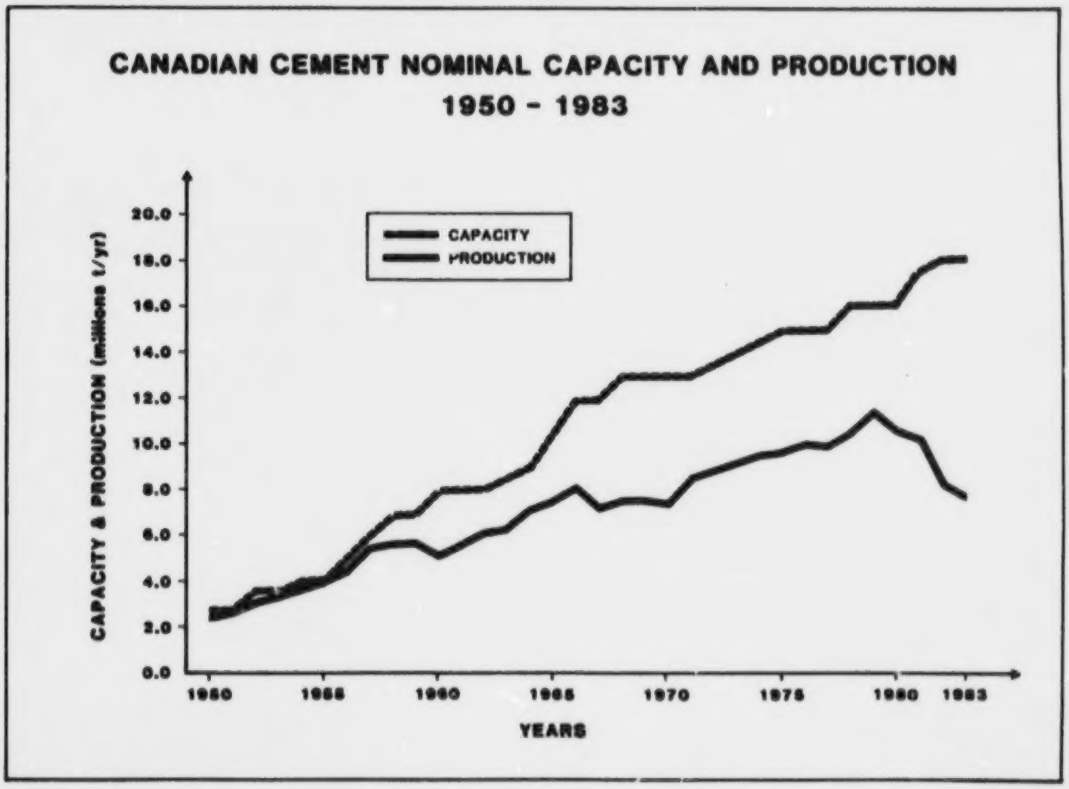
Estimated comminution power requirement by the cement industry in 1983 : 570,000,000 kWh.

Background

The Canadian cement industry has traditionally placed its plants close to markets to minimize distribution costs. The location of Canada's 23 clinker producing plants span the country with at least one in every province, excepting Prince Edward Island.

As of 1983, Canadian cement capacity was approximately 16 million tonnes. The production supplies virtually all the domestic demand. Some cement is exported to northern areas of the United States. Small quantities are imported.

The recession has had a strong impact on cement production. Capacity utilization in 1983 was in the order of 50%. Demand is expected to improve over the next few years when capital spending increases.



Source: Canada Cement Lafarge Ltd.

With the exception of oil well cements, the industry products are used in construction.

CSA CLASSIFICATION OF PORTLAND CEMENTS

NAME	TYPE	APPLICATION
Normal	10	For use in concrete construction when the special properties of the other types are not required.
Moderate	20	For use in general concrete construction exposed to moderate sulphate action, or when moderate heat of hydration is required.
High Early	30	For use when high early strength is required.
Low Heat	40	For use when low heat of hydration is required.
Sulphate-Resistant	50	For use when high sulphate-resistance is required.
Oil Well	58-59	For cementing the casing in place in oil wells.
Masonry	60	For use in bonding brick or concrete block.

The performance of a cement is controlled by a combination of physical and chemical characteristics.

The major chemical components and their typical concentrations in normal portland are as follows:

COMPOUND	INDUSTRY SYMBOL	% OF CLINKER*
Tricalcium Silicate	C_3S	55
Dicalcium Silicate	C_2S	17
Tricalcium Aluminate	C_3A	10
Tetracalcium Aluminoferrite	C_4AF	13
Minor Components		5

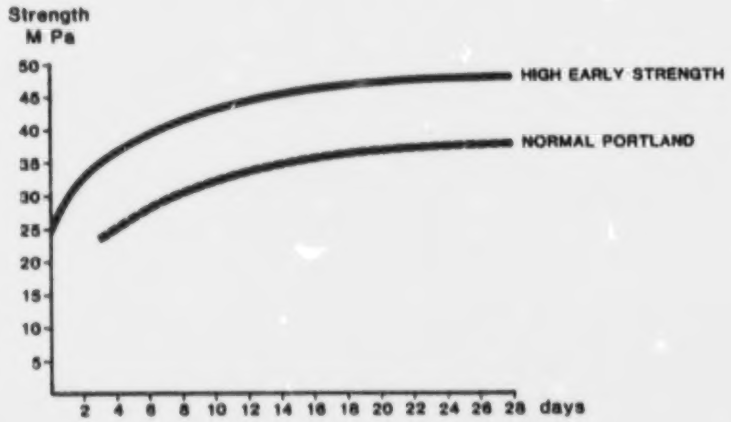
*Clinker as defined on page 33.

Most of the strength of cement is from hydration of the di and tricalcium silicates. The latter contributes to early strength development while the former contributes after about 10 days. The role of tricalcium aluminate and tetracalcium aluminoferrite are not well defined but tricalcium aluminate is believed to be involved in development of early strength.

The most important physical characteristic of cement is its fineness; the more finely ground, the more reactive the cement is; the more reactive, the greater the strength development.

The effect of fineness on compressive strength can be seen by comparing two cements, one with a high fineness and high specific surface area as measured by the Blaine method. This finer cement develops strength more rapidly than the normal product and attains a higher 28 day strength.

DEVELOPMENT OF COMPRESSIVE STRENGTH



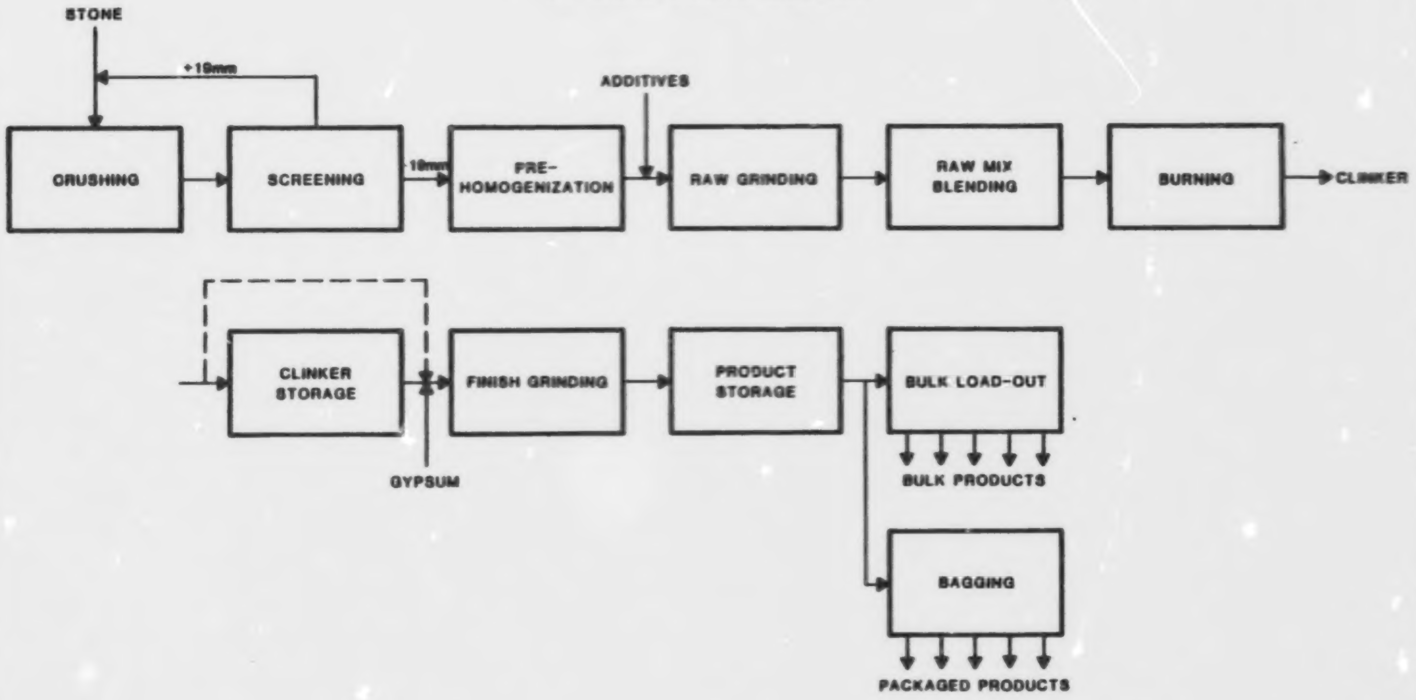
PRODUCT	PASSING 325 MESH %	BLAINE M^2/Kg
NORMAL PORTLAND	90	374
HIGH EARLY STRENGTH	96	550

The Production Process

The manufacture of Portland cement is essentially the production of high calcium silicates from limestones and silicate material such as clay or shale. The reaction is accomplished by pyroprocessing (heat-treating) a very finely-pulverized mixture of the correctly-proportioned quantities of limestone and shale.

The pyroprocessing is done in a sloping kiln, down which the raw feed flows counter-current to a stream of very hot gases from a flame at the lower end. The material leaving the kiln is known as clinker, which is pulverized with a small addition of gypsum to produce the final product - cement. Gypsum is required to control the setting and strength development of the cement when it is mixed with water and mineral aggregates to form mortar or concrete. A typical process flow sheet is shown on page 84.

PROCESS FLOW SHEET
CANADA CEMENT LAFARGE LTD
ST CONSTANT, QUEBEC


STONE
+19mm
ADDITIVES
CRUSHING
SCREENING
-19mm
PRE-HOMOGENIZATION
RAW GRINDING
RAW MIX BLENDING
BURNING
CLINKER
CLINKER STORAGE
GYPSUM
FINISH GRINDING
PRODUCT STORAGE
BULK LOAD-OUT
BULK PRODUCTS
BAGGING
PACKAGED PRODUCTS

There are two main processes:

- wet, where the raw materials are ground with water to give a slurry, of 30-35% water, which is pumped to the kiln. Because of its thermal inefficiency this process is gradually being phased out;

- dry, where the raw feed is ground and fed to the kiln dry. The St. Constant plant uses the dry process.

Variations of the dry process are the preheater and precalciner technologies, in which the raw material is preheated and precalcined in suspension before entering the kiln.

The pyroprocess by which clinker is formed involves temperatures in the material of up to 1450°C. To achieve this a flame temperature greater than 2700°C is needed. These high temperatures are normally generated by burning gas, oil or pulverized coal.

The Role of Comminution

There are three comminution steps in cement manufacture.

Crushing, where quarried rock is reduced to a size suitable for feeding to the raw mills.

Raw milling, where crushed material is ground to about 80% passing 200 mesh (75 µm) to provide the raw meal for the kiln. The actual degree of fineness at a plant is chosen to optimize the chemical reaction during pyroprocessing. Most installations use ball mills for this stage but roller mills are becoming increasingly popular, particularly in cases where the raw materials are relatively easy to grind.

Finish milling, where clinker is ground, with the addition of about 5% gypsum, to about 85-90% passing 45 μm for Normal Portland (Type 10). The purpose of the fine grinding is to ensure a suitably rapid hydration of the particles in mortar or concrete.

Comminution at the St. Constant Plant

The Crushing Circuit

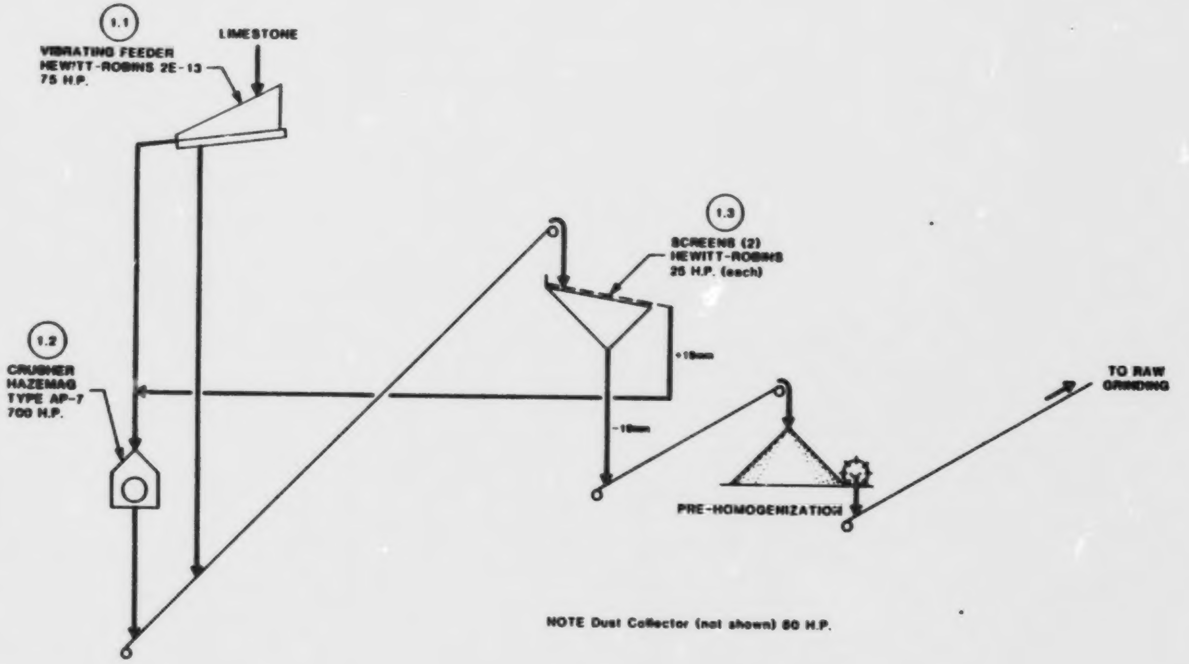
The crushing circuit is shown schematically on page 37. Power levels in kilowatts are summarized on the sketch.

The **flowrate** of the crushing department at the plant varies depending on the moisture content of the quarry-run stone. Experience has shown that the production rate varies from 400 t/h under damp, muddy conditions to 425 t/h under dry conditions. At the time of the plant visit, conditions were wet and the production rate was taken as 400 t/h.

Size distribution. Due to the size of crusher feed, no sample was taken. However, the material was estimated to have the following characteristics:

Maximum size : 1.25 m Average size : 20 cm Minus 4 cm : 30 %	Product : -19 mm

Stone from the crushing circuit is 90-95% of feed to the raw mill.


1.1
VIBRATING FEEDER
HEWITT-ROBINS 2E-13
75 H.P.
LIMESTONE
1.2
CRUSHER
HAZEMAG
TYPE AP-7
700 H.P.
1.3
SCREENS (2)
HEWITT-ROBINS
25 H.P. (each)
+19mm
-19mm
PRE-HOMOGENIZATION
TO RAW
GRINDING

NOTE Dust Collector (not shown) 80 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
1.1	Feeder	46
1.2	Crusher	404
1.3	Screens - #1	13
	#2	12
1.4	Dust Collector	54

CANADA CEMENT LAFARGE LTD. MONTREAL		
DRAWN FGM DATE 14/12/83	CRUSHING CIRCUIT FLOW DIAGRAM	PLANT of CANADA CEMENT LAFARGE ST CONSTANT, QUEBEC
CHECKED DCS DATE 20/09/84		PROJECT No. 20010

The Raw Grinding Circuit

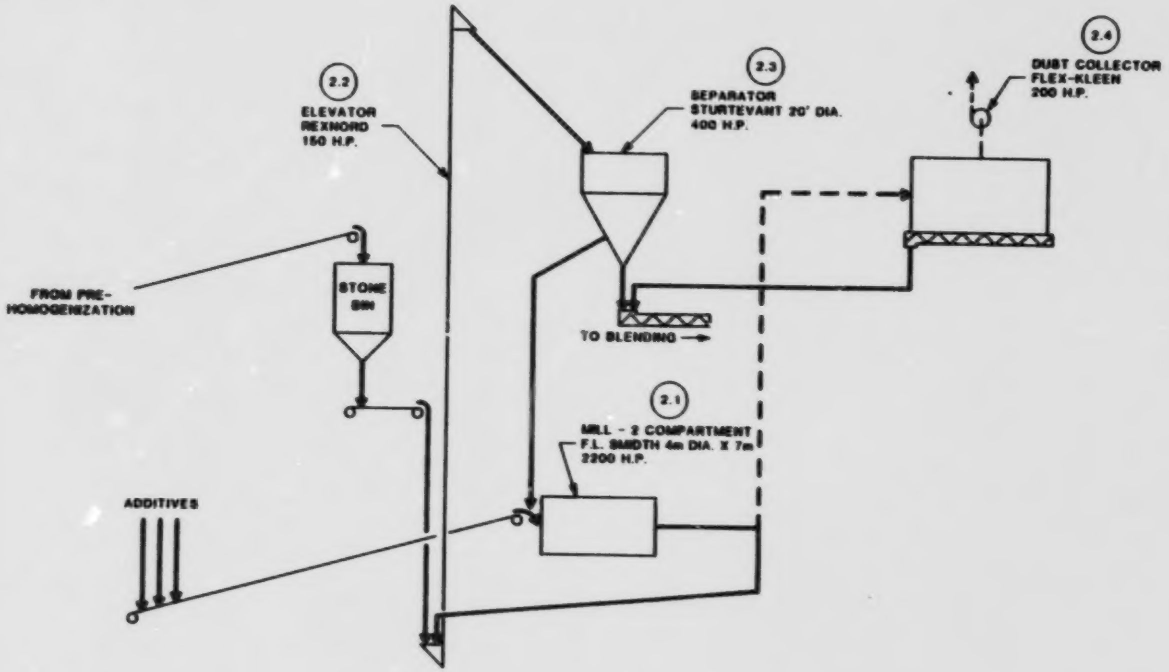
The circuit is shown schematically on page 39. Power levels in kilowatts are summarized on the sketch.

Feedrate. Stone and additive materials are each fed to the mill through separate weigh-feeders. During the period of observation, the feed rate was 116 t/h.

Grindability tests were done on the raw mix components. Coarse sand which makes up 4% or less of the mix is considerably harder to grind than the other components.

Raw Grinding - Measurements

MATERIAL	GRINDABILITY			
	BOND (kWh/Ton)	HARDGROVE INDEX	BOND (CALCULATED)	% OF RAW MIX
Limestone	10.86	60	10.48	90-95
Coarse Sand	20.77	37	16.27	2-4
Fine Sand	-	55	11.34	0.5-1
Iron	-	75	8.55	2


2.2
ELEVATOR
REXNORD
150 H.P.
2.3
SEPARATOR
STURTEVANT 20' DIA.
400 H.P.
2.4
DUST COLLECTOR
FLEX-KLEEN
200 H.P.
FROM PRE-
HOMOGENIZATION
STONE
BIN
TO BLENDING →
2.1
MILL - 2 COMPARTMENT
F.L. SMIDTH 4m DIA. X 7m
2200 H.P.
ADDITIVES

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
2.1	Mill	1635
2.2	Elevator	55
2.3	Separator	119
2.4	Dust Collector	93

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FDM
DATE 14/10/83
CHECKED DCS
DATE [illegible]

RAW GRINDING CIRCUIT
FLOW DIAGRAM

PLANT CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC

PROJECT No. 20010

Particle size of feed to the mill and product are characterized in the table below.

Raw Grinding of Mill Feed & Product
Size Distribution (% Passing)

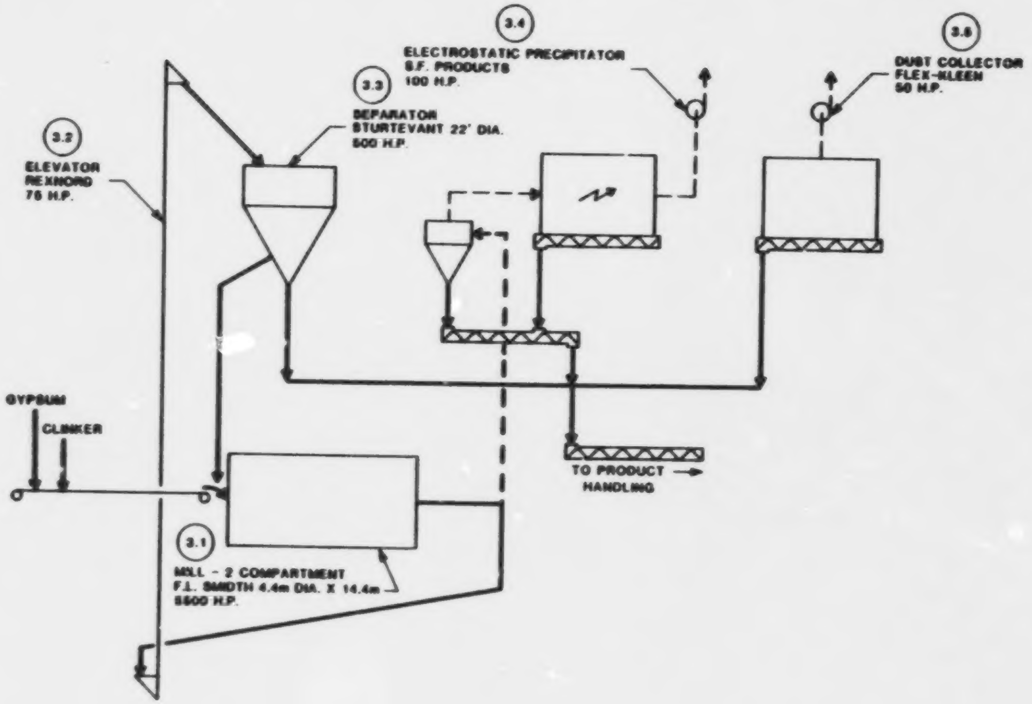
SIZE	STONE	PRODUCT
25.4 mm	100	-
19.0	97.9	-
12.7	81.8	-
9.5	67.7	-
4.75	46.6	-
2.36	32.1	-
1.18	21.7	-
600 µm	14.5	100
300	9.4	99.5
150	5.9	92.7
75	3.6	79.4
45	-	69.6
30	-	62.0
20	-	52.5
10	-	37.0
6	-	27.0
2	-	12.0

Finish Grinding

The circuit is shown schematically on page 41. Power levels are summarized on the sketch.

Flowrate. Clinker and gypsum to the finish mill are metered through individual weighfeeders. The feedrate to the mill was estimated at 95 t/h.

Grindability. Clinker was shown to have a slightly higher grindability than limestone and considerably harder to grind than gypsum.


3.2
ELEVATOR
REXNORD
75 H.P.
3.3
SEPARATOR
STURTEVANT 22' DIA.
500 H.P.
3.4
ELECTROSTATIC PRECIPITATOR
S.F. PRODUCTS
100 H.P.
3.5
DUST COLLECTOR
FLEX-KLEEN
50 H.P.
GYPSUM
CLINKER
TO PRODUCT HANDLING
3.1
MILL - 2 COMPARTMENT
F.L. SMIDTH 4.4m DIA. X 14.4m
5500 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
3.1	Mill	4303
3.2	Elevator	50
3.3	Separator	305
3.4	Precipator	45
	High Voltage - #1	3
	#2	7
3.5	Dust Collector	30

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 16/12/83
CHECKED DCS
DATE 20/09/84

FINISH GRINDING CIRCUIT
FLOW DIAGRAM

PLANT CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC

PROJECT No. 20010

Clinker and Gypsum Grindability

Material	GRINDABILITY		
	Bond (kWh/Ton)	Hardgrove Index	Bond (Calculated)
Clinker	12.01	54	11.54
Gypsum	-	98	6.71

The **particle size** distributions of the feed and product of the finish milling circuit are summarized below.

Finish Grinding
Particle Size Distribution of Mill Feed and Product
(% Passing)

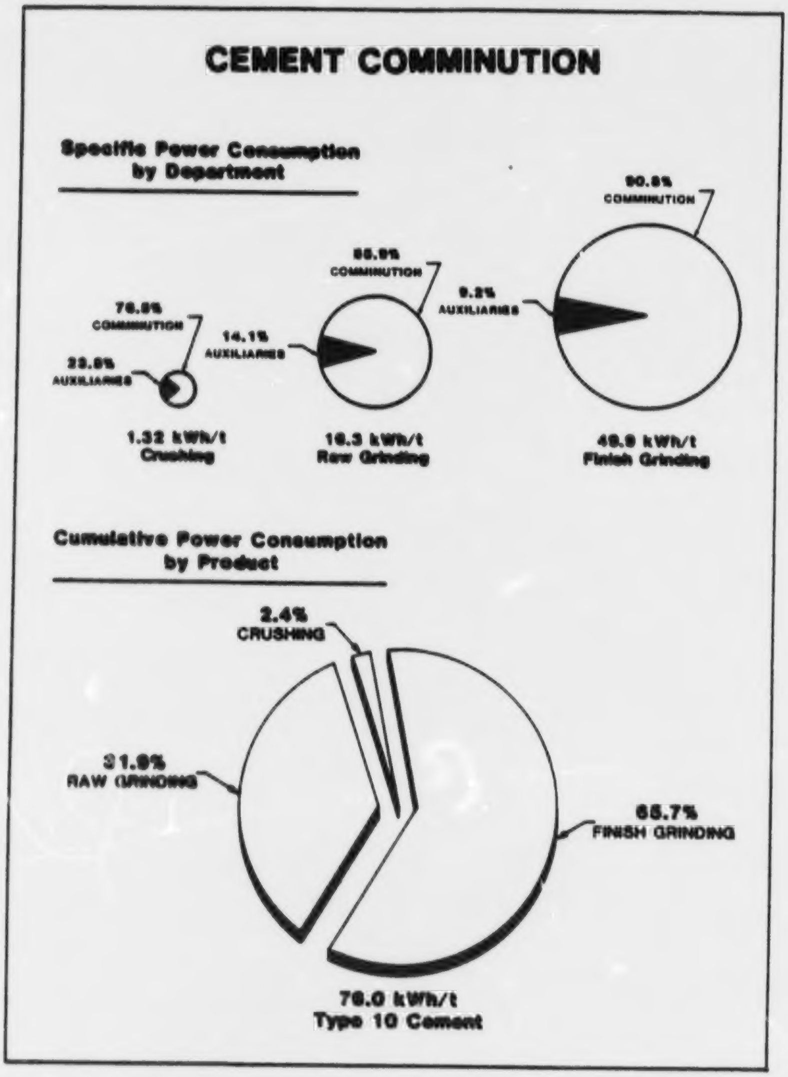
SIZE	FEED	FINISHED PRODUCT
25.4 mm	100	-
19.0	99.1	-
12.7	96.5	-
9.5	93.7	-
4.75	83.3	-
2.36	68.2	-
1.18	55.2	-
600 µm	45.8	-
300	35.9	-
150	19.9	100
75	-	96.7
45	-	85.0
30	-	69.0
20	-	54.0
10	-	34.0
6	-	22.0
2	-	8.0

It is generally accepted that the cement particles between 2 and 45 µm are responsible for strength in concrete. Particles over 45 µm only hydrate superficially and therefore contribute very little. Particles below 2 µm require additional water to coat their surfaces resulting in a higher water/cement ratio and a low contribution to strength.

Thus, 23% of the particles add minimally to the performance of the product.

Results

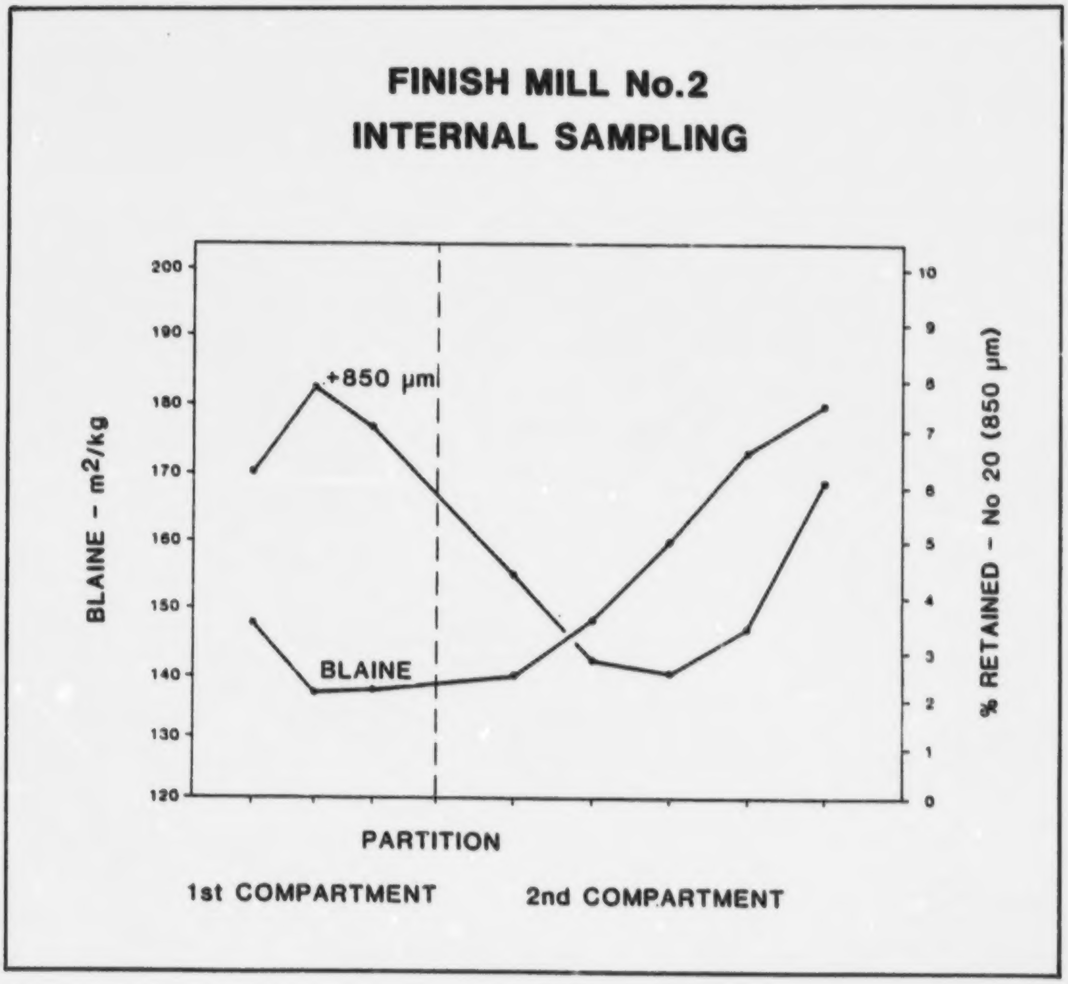
The specific power consumption in the crushing and grinding circuits are summarized in the diagram below.



The higher consumption of the finish grinding circuit can be attributed to both greater fineness of the product and higher bond grindability index of the feed.

The results are believed to be representative of power consumption by the industry as a whole. However, because of the large power demand in finish grinding, a number of checks were run on the degree of optimization of the mill circuit at the plant.

Internal Sampling. The mill was "crash" stopped, and samples were taken to record the passage of fine and coarse material through the two compartments. The results are graphed below.



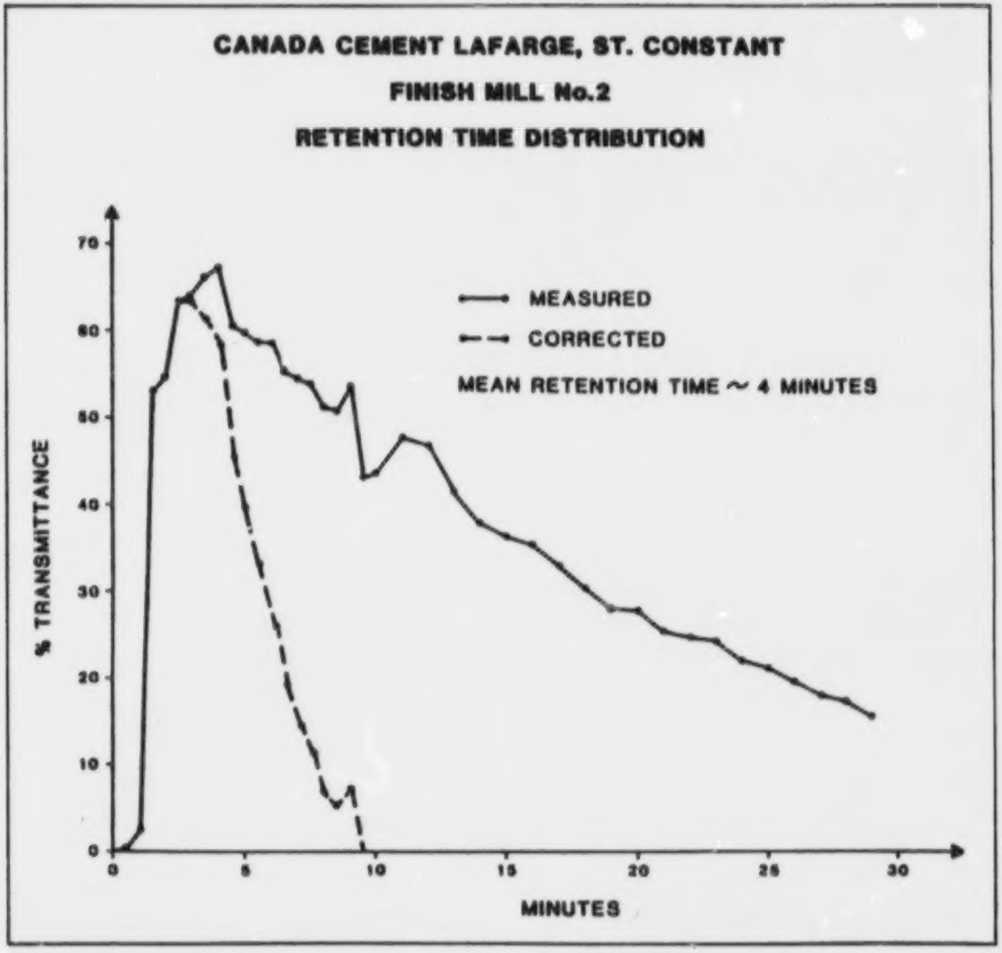
Ideally, grinding of coarse material should occur in the first compartment while generation of fine material should occur in the second. The results show considerable coarse grinding taking place after the partition (+850 μm curve) with a build-up of coarse material near the discharge grates.

The Blaine curve is typical for a two compartment mill. The sample closest to the mill inlet is not considered representative, due to a flush of reject material into the mill from the separator, after the system was "crash" stopped.

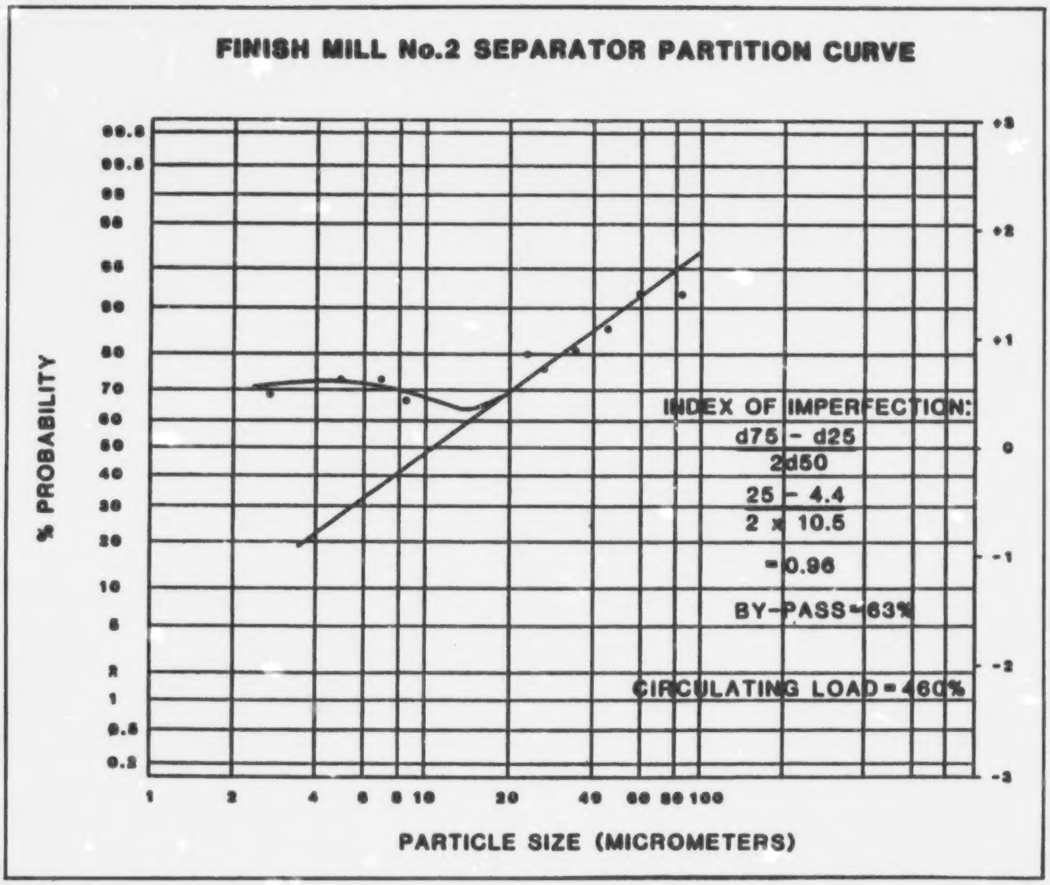
The results indicate a deficiency in the partition allowing excessively coarse material into the second compartment which is not equipped to grind it. Visual inspection of the partition showed some gaps in the grates requiring repairs. The build-up of coarse material in the second compartment is a result of the material being held back by the discharge grates.

Residence time tests confirmed that material was being held up in the mill.

A pulse of dye was put into the inlet of the mill at time zero and the mill discharge was sampled at regular intervals. Dye concentration in the discharge gives retention characteristics of the mill. The theoretical retention time distribution curve corrects for recycle of dye through the reject stream. The resulting mean retention time was found to be longer than is usually experienced on this mill.


CANADA CEMENT LAFARGE, ST. CONSTANT
FINISH MILL No.2
RETENTION TIME DISTRIBUTION

Air separator performance was checked giving the partition curve shown below.



The partition curve represents the probability of a particle of a given size ending up in the reject stream. The index of imperfection is inversely related to the steepness of the sloped part of the curve. The flat part of the curve is the by-pass where particles have a more or less equal probability of being rejected regardless of size.

The results indicate that separator performance was not optimal; both the index of imperfection and by-pass being high. Internal inspection of the separator revealed repair work needed on selector blades and table. Repairs to finish mill partition and separator are expected to improve separation efficiency, reduce circulating load and specific energy consumption.

Conclusions

The finish milling circuit was not operating under optimal conditions during the test but the overall results nonetheless can be used as a fair representation of power consumption in the comminution stages of cement manufacture.

It is concluded that power consumption could be reduced,

- in the short term, by continued optimizing of existing milling circuits,
- in the medium term, by introduction of improved classification so that the over and undersized particles are eliminated. Up to 25% of finish grinding energy could be saved,
- in the long term, by introduction on new types of mills with better grinding efficiences. The large investment by the industry in conventional mills will tend to retard this approach.

[illegible]
PROCÉDÉ *Plandex* X PROCESS
MONTRÉAL QUÉBEC

GYPSUM

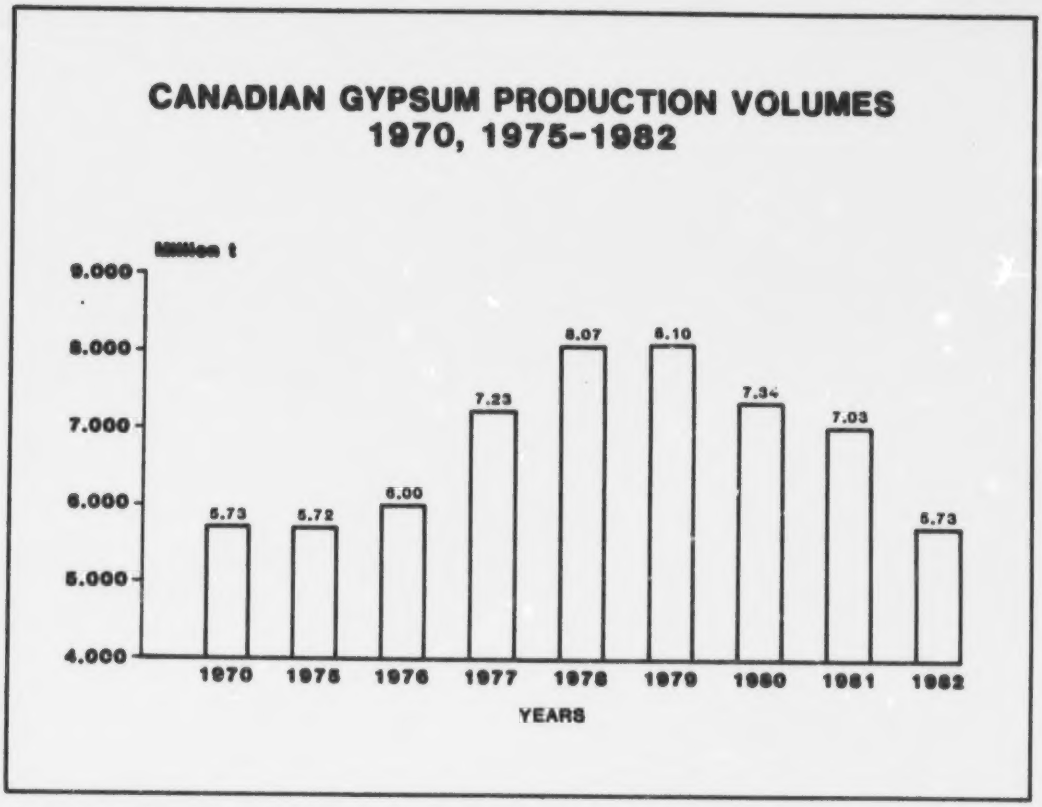
Participating Company

DOMTAR INCORPORATED

Plant Location

Caledonia, Ontario

Gypsum: Low Energy Consumption for Comminution



Source: Canadian Minerals Yearbook 1982, EMR Canada.

Average comminution power requirement : 18.4 kWh/t.

Estimated comminution power requirement by the gypsum industry in 1982 : 45,000,000 kWh.

Background

The principal location of Canada's gypsum industry is the province of Nova Scotia which accounts for about three-quarters of Canadian production. Gypsum products are manufactured in every province except New Brunswick and Prince Edward Island.

Canada is the world's second largest producer, and exports about 70% of its production to the United States as crude gypsum. Imports in the form of wallboard from the U.S. have declined greatly during the last few years. Output of gypsum products is directly linked to construction activity.

Products and Uses

Gypsum has the property of being able to release associated water at relatively low temperatures to form hemi-hydrate and to regain water to form gypsum. During re-hydration, the gypsum "sets" to form an insulating, fire-retardant board, used in building construction.

The main impurities in commercial gypsum are limestone, shale, or clay. The amount of impurities which can be tolerated depends on the type of impurity, and the final product.

The major chemical components of pure gypsum and anhydrite are:

Component	Pure Gypsum	Anhydrite
Combined Water	20.9%	-
Sulphur Trioxide (SO_3)	46.6%	58.8%
Lime (CaO)	32.5%	41.2%

Uses of crude (uncalcined) gypsum include manufacture of Portland cement, where gypsum acts as a retarder to control setting rate, as a filler in paint or paper manufacture, a substitute for salt cake in glass manufacture, and as a soil conditioner.

The Production Process

Gypsum processing involves the reduction of gypsum ore by crushing and grinding and subsequent formation of the hemi-hydrate by calcining. The pyroprocessing is by batch. A charge of crude gypsum is fed into a kettle equipped with an agitator, heated until the material temperature reaches about 160°C and water vapour is driven off to form the hemi-hydrate. The calcined gypsum, called "stucco", can be packaged and sold as a finished product to be used as plaster. Most of the stucco, however, is used to make gypsum board. A slurry of stucco and water is prepared and immediately placed between two layers of paper in a continuous process. The gypsum "sets" rapidly and the board is cut, dried, and palletized in preparation for shipment as finished product. A typical process flow sheet is shown overleaf.

The Role of Comminution

There are two comminution steps in the gypsum process.

Crushing, where mined ore is reduced to a size suitable for feeding to the mill. The crushed ore is also dried of surface moisture.

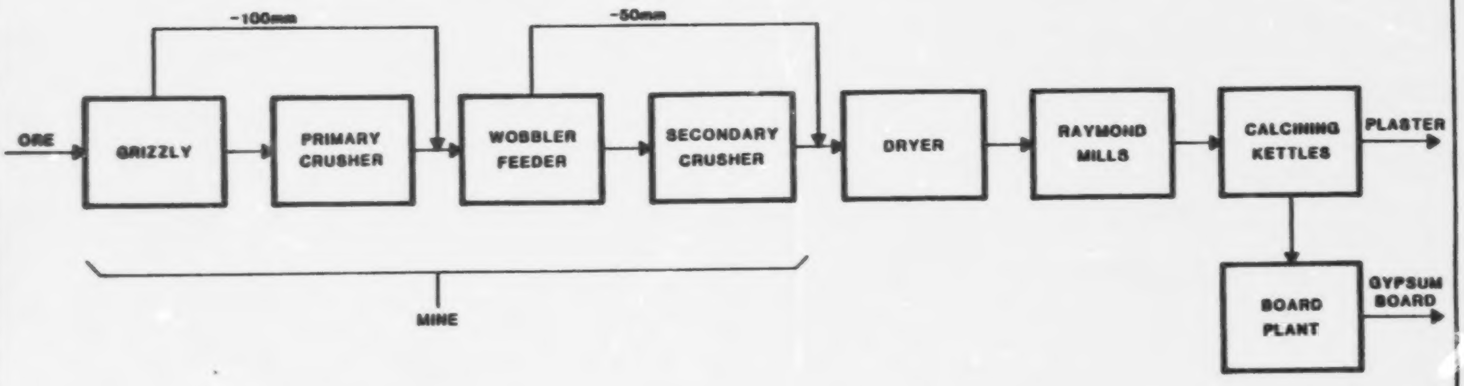
Milling, where crushed material is reduced to about 95% minus 150 μm for feeding to the calcining kettles.

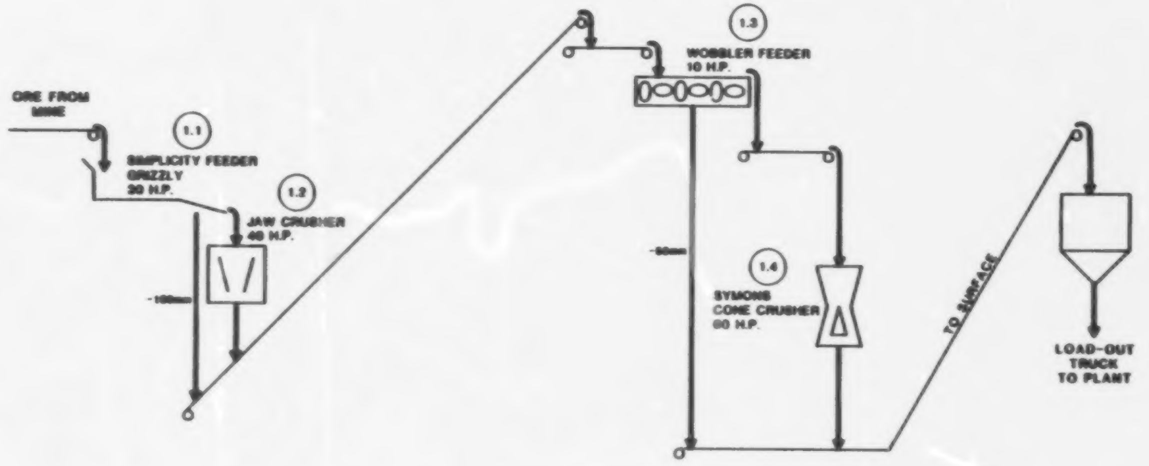
Comminution at the Caledonia Plant

The Crushing Circuit

The crushing circuit is shown schematically on page 53. Rated power (HP) and average demand (kW) in operation are summarized on the sketch.

PROCESS FLOW SHEET
DOMTAR GYPSUM DIVISION
CALEDONIA, ONTARIO


-100mm
-50mm
ORE
GRIZZLY
PRIMARY CRUSHER
WOBBLER FEEDER
SECONDARY CRUSHER
DRYER
RAYMOND MILLS
CALCINING KETTLES
PLASTER
BOARD PLANT
GYPSUM BOARD
MINE


ORE FROM MINE
1.1
SIMPLICITY FEEDER GRIZZLY 30 H.P.
1.2
JAW CRUSHER 40 H.P.
-100mm
1.3
WOBBLER FEEDER 10 H.P.
-50mm
1.4
SYMONS CONE CRUSHER 60 H.P.
TO SURFACE
LOAD-OUT TRUCK TO PLANT

NOTE: Aspiration Fan (not shown) 10 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
1.1	Simplicity Feeder	8.5
1.2	Jaw Crusher	10.1
1.3	Wobbler Feeder	2.1
1.4	Cone Crusher	29.7
1.5	Aspiration Fan	10.4

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 01/08/84
CHECKED DCS
DATE 20/09/84

GYPSUM CRUSHING
FLOW DIAGRAM

PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.

PROJECT No. 20010

The **production rate,** at the time power demand measurements were taken, was 210 t/h.

Size distribution. Ore feed to the crushing circuit was estimated to be minus 300 mm with most of the material being minus 150 mm. The circuit product was minus 75 mm.

The **Hardgrove grindability** index was determined to be 61 with a calculated Bond Work Index of 10.32 kWh/Ton.

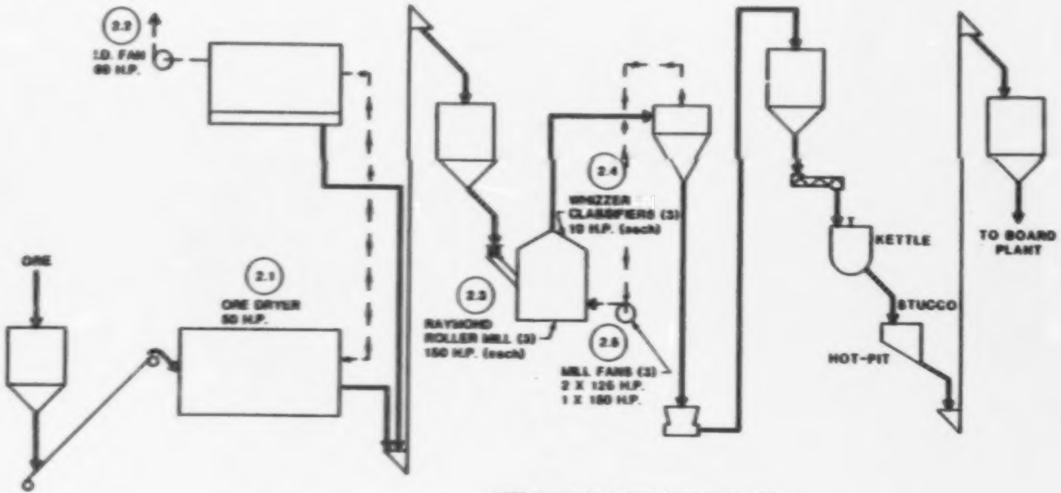
The Grinding Circuit

The circuit is shown schematically on page 55. Rated power and average demand are summarized on the sketch.

Flowrate. The circuit is made up of 3 mills operating in parallel. The combined production rate of the circuit was 41 t/h.

Size distribution. Feed to the mills and circuit product is characterized in the table below.

	% Passing	
Size	Feed	Product
75 mm	100	
50	90.5	
25	61.9	
12.5	40.0	
1.18	11.4	
425 µm		100
150	3.8	93.0
106		84.5
75		78.3
45		75.5
20		63.0
10		48.0
2		13.5


2.2
I.D. FAN
60 H.P.
ORE
2.1
ORE DRYER
50 H.P.
2.3
RAYMOND
ROLLER MILL (3)
150 H.P. (each)
2.4
WHIZZER
CLASSIFIERS (3)
10 H.P. (each)
2.5
MILL FANS (3)
2 X 125 H.P.
1 X 150 H.P.
KETTLE
STUCCO
HOT-PIT
TO BOARD
PLANT

NOTE: Mill Dust Collector (not shown) 60 H.P.

POWER MEASUREMENT CALCULATIONS			
No.	EQUIPMENT		kW AVG.
2-1	Dryer		21.7
2-2	I.D. Fan		26.3
2-3	Raymond Mill	#1	135
		#2	118
		#3	115
2-4	Whizzer	#1	3.7
		#2	3.3
		#3	4.5
2-5	Fan	#1	95.2
		#2	96.3
		#3	103
2-6	Dust Collector		17.6

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE [illegible]
CHECKED DCS
DATE 29/08/84

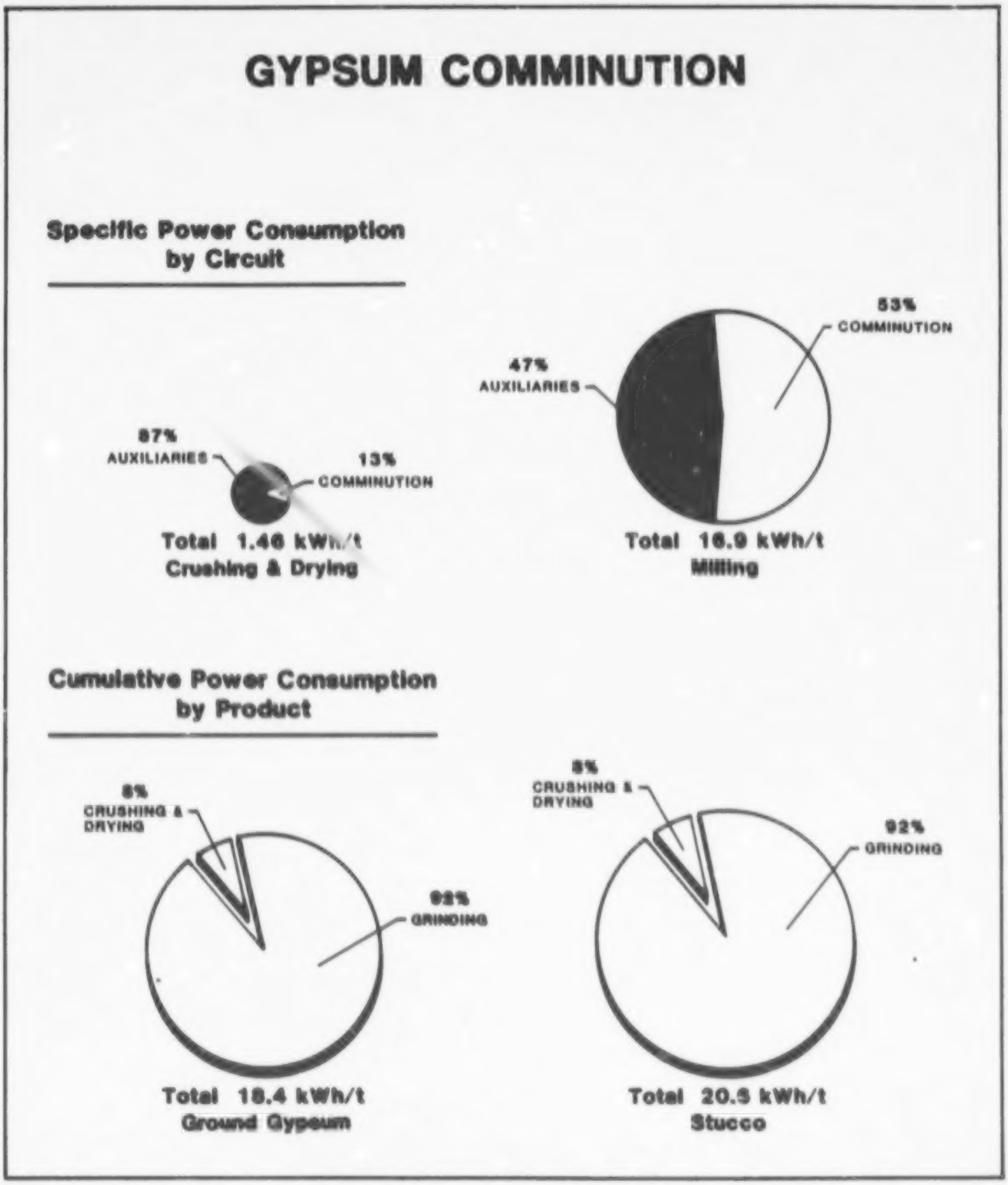
GYPSUM GRINDING + CALCINING
FLOW DIAGRAM

PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.

PROJECT No. 20010

Results

The specific power consumption in the crushing and grinding circuits is summarized as follows:



Energy consumption by comminution and associated operations in the gypsum process is relatively low compared to other industrial minerals. This is due to the low grindability index of gypsum and the coarseness of the ground product.

Cumulative specific consumption for stucco accounts for a yield factor of 89% in the calcination step due to water loss.

Conclusions

Comminution, itself, accounts for a relatively small proportion of consumption for crushing and drying. The two crusher motors are not heavily loaded. Auxiliary energy demand includes consumption by dryer drive and draft fan.

Milling consumption is about evenly divided between comminution and auxiliaries. Despite the fineness target of 95% passing 150 µm, nearly half the mill product was determined to be minus 10 µm. This over grinding may be a result of high circulating load which is evidenced by the heavy loading of the fan motors. However, plant experiments have shown the best production rate with both mill and fan motors running at capacity. A roller mill does not seem to be the most suited milling equipment.

The results were obtained under typical plant operating conditions and are believed to be representative of the industry.

Recommendations

None.

[illegible]
[illegible] Flanders & [illegible]
[illegible]

LIME

Participating Company

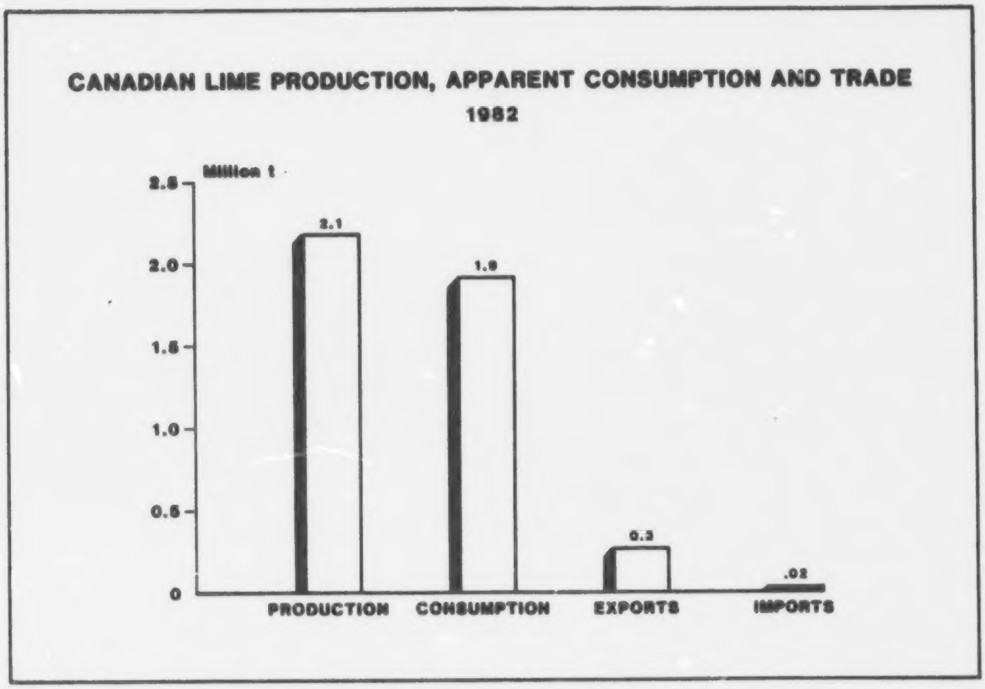
DOMTAR INCORPORATED *

Plant Location

Joliette, Quebec

* Joliette plant now owned by Jolichaux Inc.

Lime: Low Specific Power Consumption - Large Tonnages



CANADIAN LIME PRODUCTION, APPARENT CONSUMPTION AND TRADE
1982

Source: Canadian Minerals Yearbook 1982, EMR Canada.

Average comminution power requirement* : 2.8 kWh/t.

Estimated comminution power requirement by the lime industry in 1982 : 6,000,000 kWh.

Background

Lime is a high-bulk, low-cost commodity. Thus, plants are generally located close to markets and adjacent to a source of suitable limestone. The industrialized provinces, Ontario and Quebec, together produce about 80% of Canadian lime output.

---

* Assuming that steelworks lime is 50% of industry production.

The production figures shown below do not include captive capacity, of pulp and paper plants, which burn sludge to recover lime for re-use.

Canadian lime capacity is estimated to be about 3-5 million tonnes per year. Current demand is considerably below this level because of current economic conditions.

Lime, as shown in the table below, has a wide range of applications.

Canada, Consumption of Lime, Quick and Hydrated, 1981 (Producers' Shipments and Quantities Used by Producers, By Use)

	1981P	
	(tonnes)	%
Chemical and metallurgical		
Iron and steel plants	1 237 519	48.5
Pulp and paper mills	271 945	10.6
Water and sewage treatment	22 760	6.5
Nonferrous smelters	117 632	
Cyanide and flotation mills	(4)	
Sugar refineries	25 841	
Other industrial	690 040	27.0
Agricultural	17 370	7.4
Road stabilization	9 338	
Other uses	162 555	
Total	2 555 000	100.0

Source: Statistics Canada; Energy, Mines and Resources, Canada.

Steel-making lime specifications require a low sulphur content, generally below 0.1%. Typical particle size range for this product is between 50 and 5 mm.

Lime sold for other uses normally has a maximum permissible sulphur level and a particle size specified to match the chemical reactvity required by the user.

Hydrated lime which accounts for less than 10% of production is mainly used in water treatment by smaller scale consumers who do not have slaking equipment.

The Production Process

A general process flow sheet for lime manufacture is illustrated. Lime manufacture can be simplified into three basic steps:

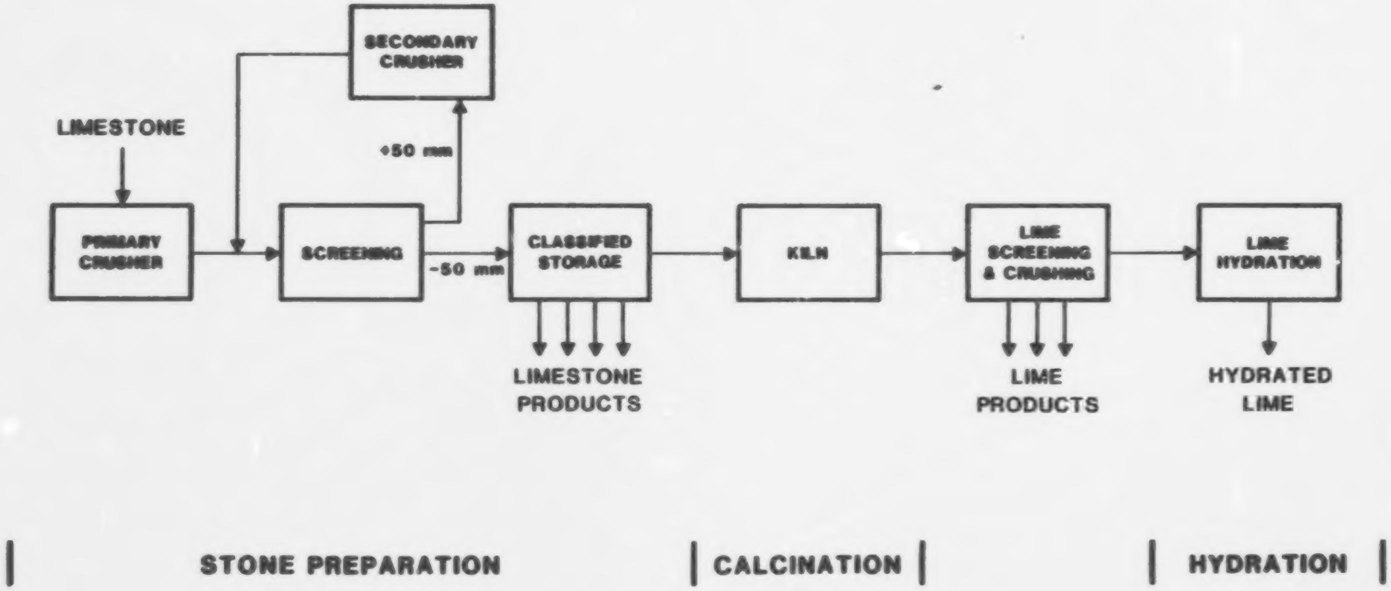
- Stone preparation (kiln feed).
- Calcination.
- Lime hydration.

Hydrated lime production requires additional process steps:

- crushing the quicklime,
- mixing the quicklime with water,
- removal of impurities and uncalcined limestone by air classification.

LIME PROCESS FLOW SHEET

DOMTAR JOLIETTE PLANT


LIMESTONE
PRIMARY CRUSHER
SCREENING
SECONDARY CRUSHER
+50 mm
-50 mm
CLASSIFIED STORAGE
LIMESTONE PRODUCTS
KILN
LIME SCREENING & CRUSHING
LIME PRODUCTS
LIME HYDRATION
HYDRATED LIME
STONE PREPARATION
CALCINATION
HYDRATION

The Role of Comminution

There are two comminution stages in lime manufacture and both involve crushing.

Limestone crushing, where the quarried rock is reduced to a suitable size for kiln feed, which is made up of given proportions of different sizes of limestone from classified storage. The size of the feed determines the size distribution of the quicklime after calcination.

Lime crushing, where the purpose is to reduce the quicklime to the particle size specified by consumers or to prepare it for hydration.

Comminution at the Joliette Plant

The Limestone Crushing Circuit

The circuit is shown schematically on page 63 with power demand in kilowatts summarized on the sketch.

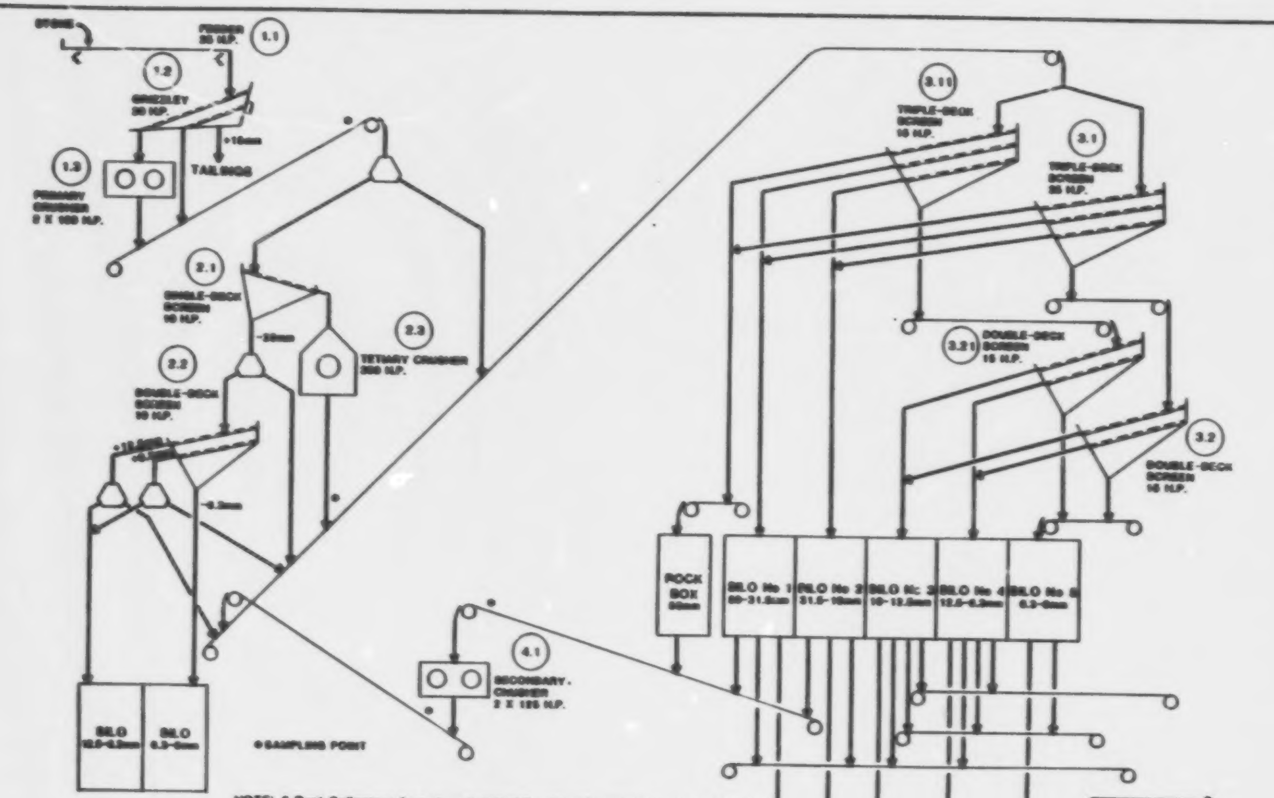
The circuit is used in production of limestone products as well as kiln feed.

The **flowrate,** at the primary crusher, of 493 t/h was estimated from a quarry truckload count.

Flowrate to the secondary crusher was estimated to be 152 t/h.

Grindability tests showed the limestone to have a Hardgrove Index (HGI) of 83 and a Bond Index of 8.86 kWh/ton.

A typical HGI for limestone is in the range 50-70, giving an average calculated Bond Index of 10.48 kWh/ton.


STONE
FEEDER 30 H.P.
1.1
1.2
GRIZZLEY 30 H.P.
+10mm
TAILINGS
1.3
PRIMARY CRUSHER 2 X 100 H.P.
2.1
DOUBLE-DECK SCREEN 10 H.P.
-30mm
2.3
TETIARY CRUSHER 300 H.P.
2.2
DOUBLE-DECK SCREEN 10 H.P.
+12.5mm
+6.3mm
-6.3mm
SILO 12.5-6.3mm
SILO 6.3-0mm
● SAMPLING POINT
4.1
SECONDARY CRUSHER 2 X 125 H.P.
3.11
TRIPLE-DECK SCREEN 15 H.P.
3.1
TRIPLE-DECK SCREEN 35 H.P.
3.21
DOUBLE-DECK SCREEN 15 H.P.
3.2
DOUBLE-DECK SCREEN 15 H.P.
ROCK BOX 50mm
SILO No 1 50-31.5mm
SILO No 2 31.5-19mm
SILO No 3 19-12.5mm
SILO No 4 12.5-6.3mm
SILO No 5 6.3-0mm

NOTE: 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
1.1	Feeder	2
1.2	Grizzley	8
1.3	Primary Crusher	90 122
1.4	Dust Collector	51
2.4	Tert. Crusher Dust Collector	52
3.1	Triple-Deck Screen	8.9
3.11	Triple-Deck Screen	6.7

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
3.2	Double-Deck Screen	4.5
3.21	Double-Deck Screen	4.5
3.3	Dust Collector (Screens)	32
3.4	Dust Collector (Conveyors)	11.4
4.1	Secondary Crusher	18 28
4.2	Dust Collector	26

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LIMESTONE CRUSHING & SCREENING
FLOW DIAGRAM

PLANT of PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010

Size distribution. Crusher feed size range was minus 1250 mm, plus 150 mm. Most of the material was between 600 mm and 300 mm.

The primary crusher product was not sampled directly but was derived from an approximate material balance of the circuit.

PRIMARY CRUSHER PRODUCT SIZE DISTRIBUTION

mm	% passing
150	100
100	94
50	72
25	45
12.5	25
6.3	12

The secondary crusher feed and product size distributions were both sampled. The following table summarizes the size distributions.

SECONDARY CRUSHER FEED AND PRODUCT SIZE DISTRIBUTIONS

mm	% feed passing	% product passing
132.5	100	
100	80	
75	60	100
50	13	87
38.1	3	79
25		58
19		46
12.5		31
9.5		24

Crushing circuit product size distribution is as follows.

CIRCUIT PRODUCT SIZE DISTRIBUTION	
mm	% passing
50	100
31.5	86
19	64
12.5	41
6.3	20

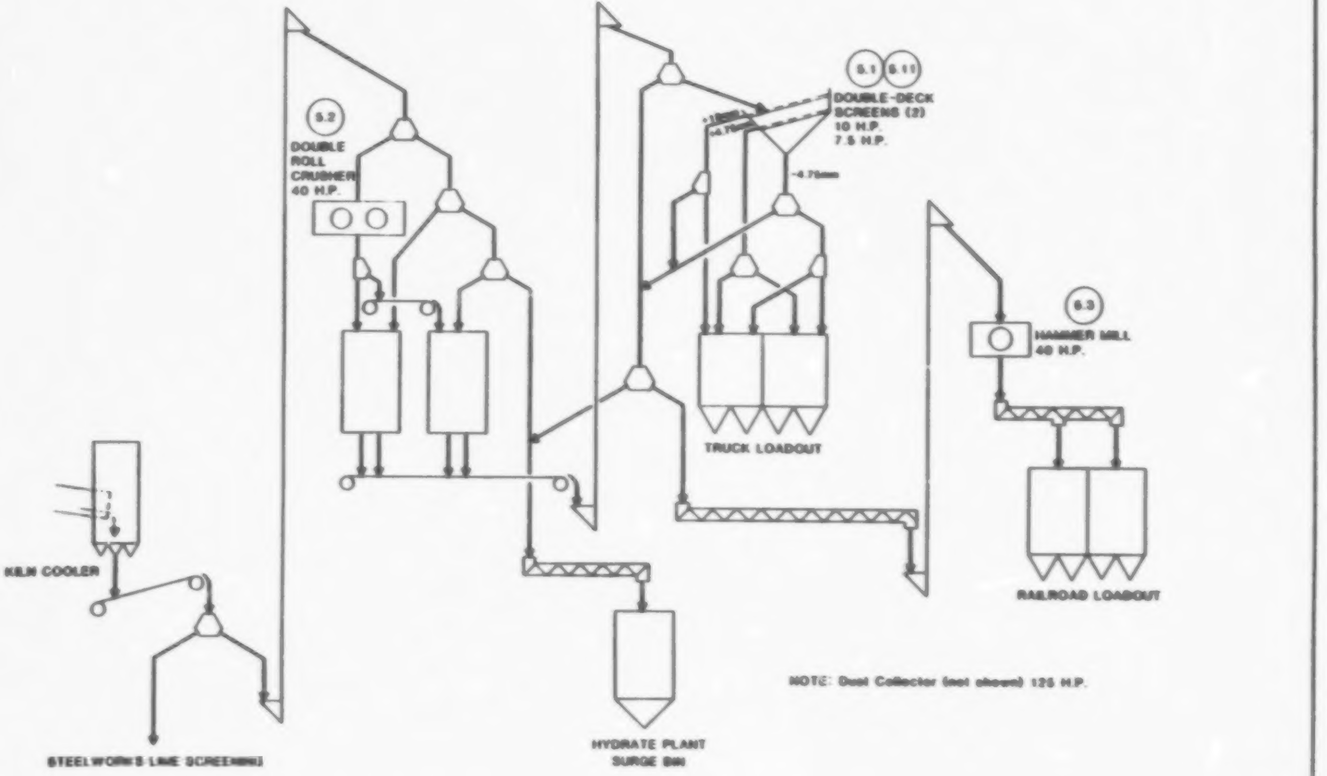
Lime Crushing Circuits

The essential steps of lime processing are shown in the accompanying flow diagrams. One product, steelworks lime, does not require crushing but is screened to remove fines. The other products, 3/16 inch lime and hydrated lime are both crushed.

The flowrates through the systems are summarized.

LIME FLOWRATES	
PROCESS UNIT	t/h
Raw Lime Screening	14.5
3/16 Inch Lime Crushing	8.5
Steelworks Lime - 1st Screening	16.8
Steelworks Lime - 2nd Screening	136
Hydrate Plant	14.5

Grindability tests on lime by both the Hardgrove and Bond procedures were conducted. The test results, as expected, show lime to be extremely easy to grind. The Hardgrove Index (HGI) was determined to be 165. The Bond test gave a value of 4.2 kWh per short ton.


5.2
DOUBLE ROLL CRUSHER 40 H.P.
5.1
5.11
DOUBLE-DECK SCREENS (2) 10 H.P. 7.5 H.P.
+19mm
+4.75mm
-4.75mm
5.3
HAMMER MILL 40 H.P.
KILN COOLER
TRUCK LOADOUT
RAILROAD LOADOUT
HYDRATE PLANT SURGE BIN
STEELWORKS LIME SCREENING

NOTE: Dust Collector (not shown) 125 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
5.1	Double-Deck Screen	3.2
5.11	Double-Deck Screen	3.5
5.2	Double Roll Crusher	4.5
5.3	Hammer Mill	7.0
5.4	Dust Collector	70.0

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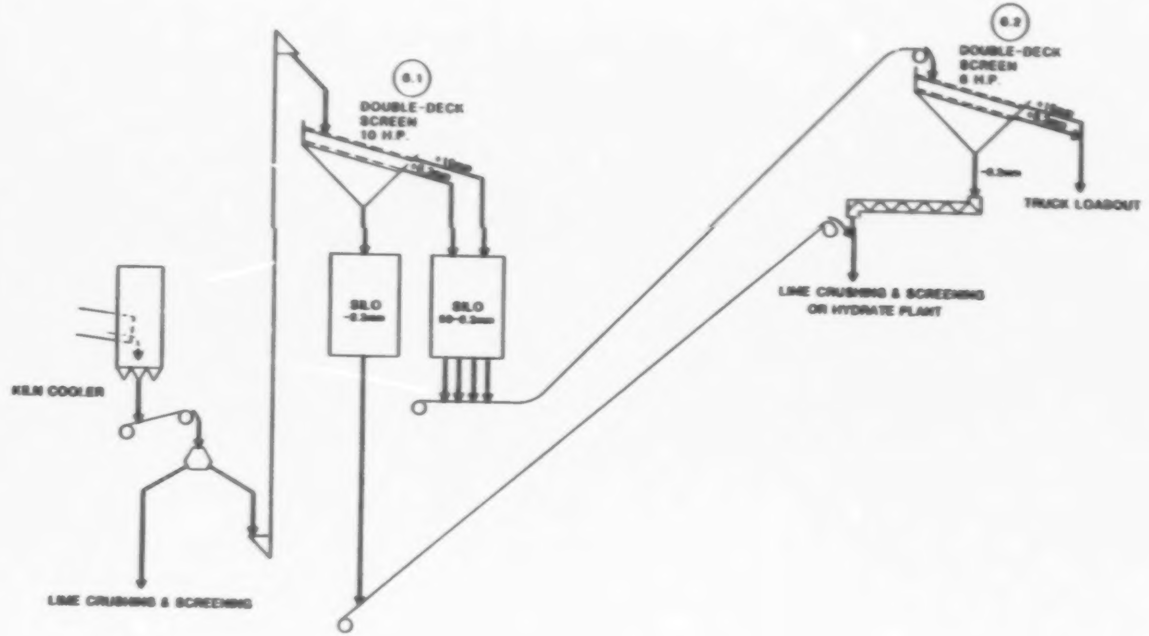
LIME CRUSHING & SCREENING
FLOW DIAGRAM

PLANT N° PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010


6.1
DOUBLE-DECK SCREEN 10 H.P.
6.2
DOUBLE-DECK SCREEN 8 H.P.
SILO
SILO
KILN COOLER
LIME CRUSHING & SCREENING
LIME CRUSHING & SCREENING OR HYDRATE PLANT
TRUCK LOADOUT

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
6-1	Double-Deck Screen	3.0
6-2	Double-Deck Screen	3.5

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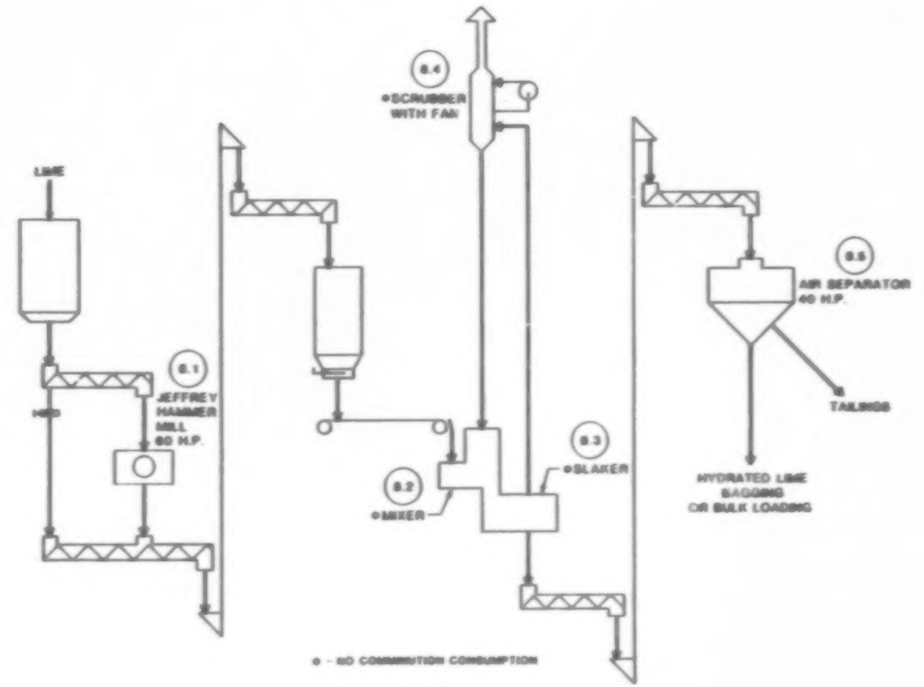
STEELWORKS LIME SCREENING
FLOW DIAGRAM

PLANT of PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010


LIME
8.1
JEFFREY
HAMMER
MILL
60 H.P.
8.4
*SCRUBBER
WITH FAN
8.2
*MIXER
8.3
*SLAKER
8.5
AIR SEPARATOR
40 H.P.
TAILINGS
HYDRATED LIME
BAGGING
OR BULK LOADING

* - NO COMMINUTION CONSUMPTION

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
8-1	Hammer Mill	14.0
8-2	Mixer	-
8-3	Slaker	-
8-4	Scrubber with Fan	-
8-5	Air Separator	15.6

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HYDRATED LIME PLANT
FLOW DIAGRAM

PLANT OF PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010

Size distribution. Crushing is used to produce minus 4.75 mm (3/16") lime and also in preparation of lime for hydration.

In the production of minus 4.75 mm lime, the feed to the crusher consists of two thirds of a plus 19 mm fraction and one third of a minus 4.75 mm fraction. This feed results from the screening of raw lime whereby the mid-fraction is extracted and sold as a product.

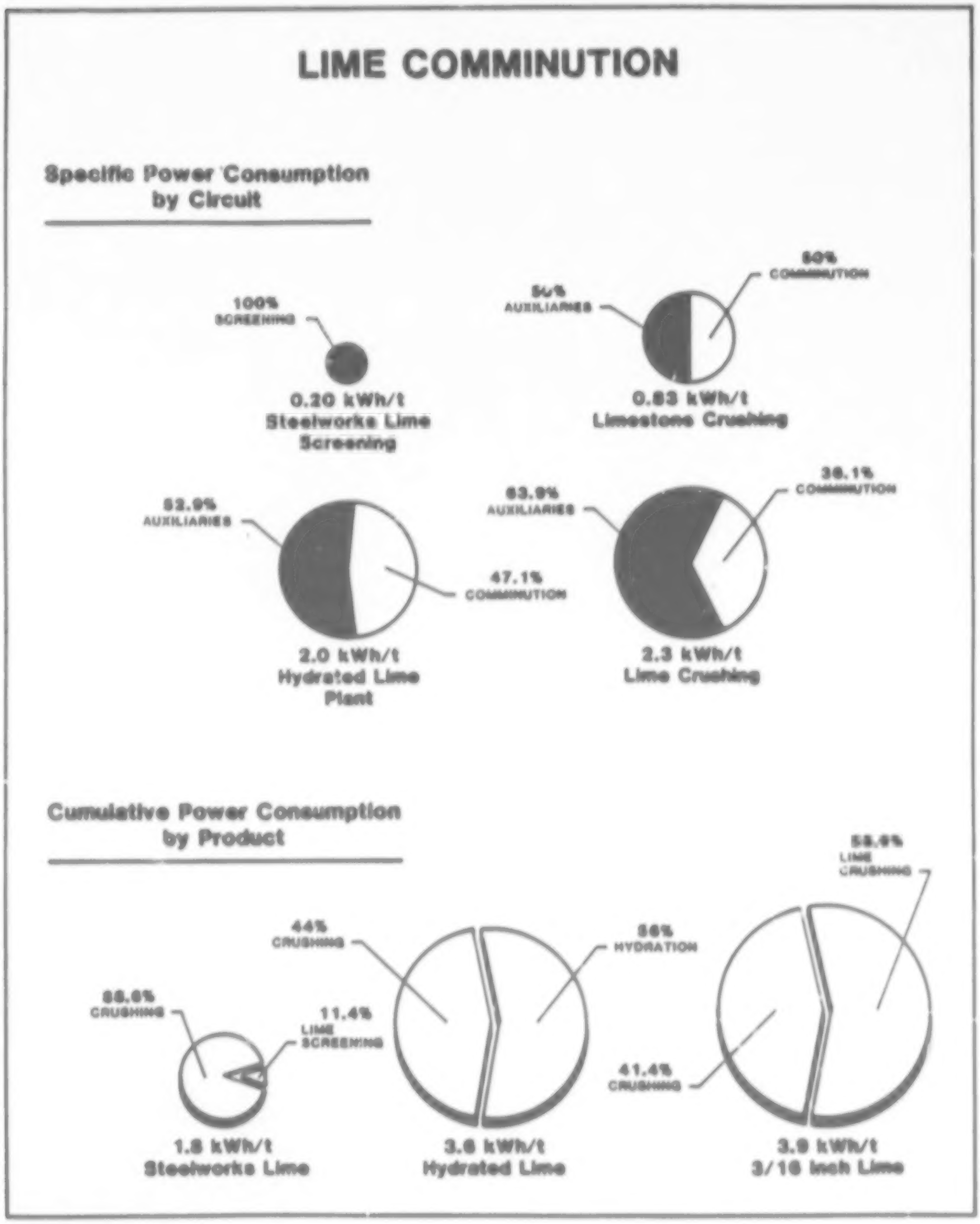
The crushed product had the following size distribution:

3/16 INCH LIME SIZE DISTRIBUTION	
Size (mm)	% Passing
6.70	100
4.75	95
2.36	80
1.18	65
0.60	45

For lime used for hydration, the feed to the crusher can be a raw kiln product, a screened fraction or fines recuperated from dust collection. The fineness of the crushed lime is minus 2.36 mm.

Results

The specific power consumption by circuit and by product, as shown in the diagram below, emphasize the small amounts of power required in comminution.



From plant records, total power consumption was estimated to average 31 kWh/tonne of product. Assuming 3 kWh/tonne, comminution including auxiliaries represents about 10% of the total electric power consumption.

Savings could be had by reducing air flows through the dust collectors when the crushers are idling. A system could be engineered that would automatically close down dampers during idle periods. This would reduce power demand on fan motors for an appreciable amount of time.

Conclusions

The average power consumption for comminution per tonne, including auxiliaries, in the lime industry is low; just under 4 kWh. Moreover, a large part of the calcined product does not require crushing but only screening to remove fines (steelworks lime).

In summary, there appears to be no great potential for electrical energy savings in the lime industry. But the study has brought out the importance of the power consumption attributable to air pollution control. This was established clearly in limestone crushing and screening where dust collection accounts for 42% of total power consumption.

Recommendation

Significant comminution energy savings would be difficult to achieve for this mineral due to the low consumption.

LIMESTONE

[illegible] Plandex PROCESS
MONTREAL, QUEBEC

LIMESTONE

Participating Companies

DOMTAR INCORPORATED *

Plant Location

Joliette, Quebec

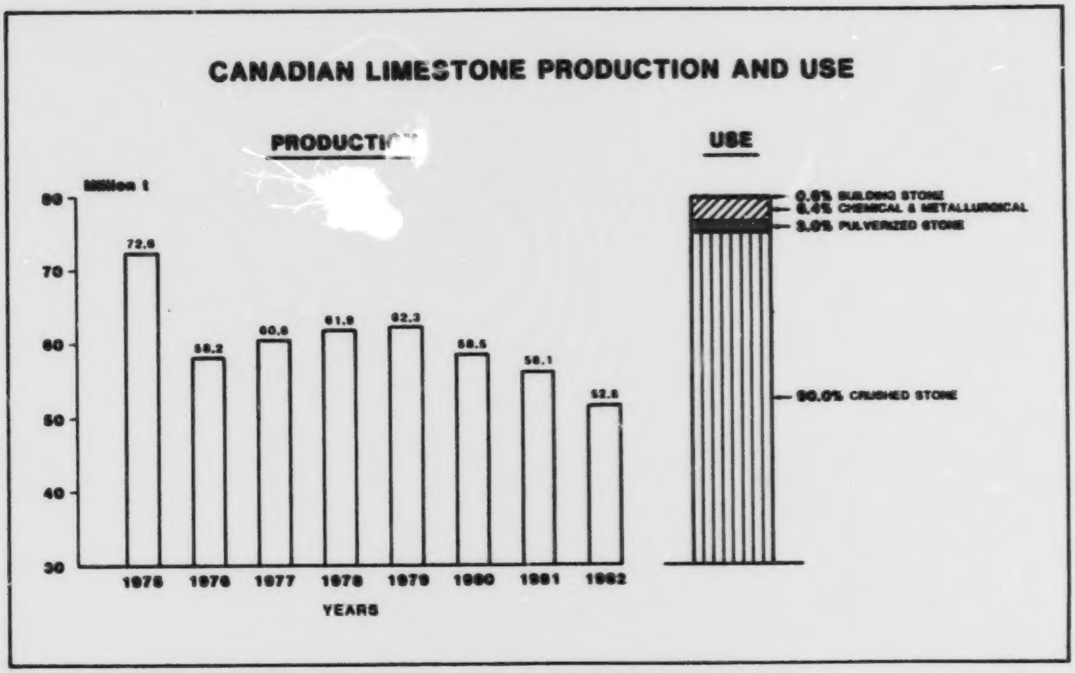
STEEP ROCK RESOURCES INCORPORATED

Plant Location

Perth, Ontario

* Joliette plant now owned by Jolichaux Inc.

Limestone: Large tonnages of low power consumption products



CANADIAN LIMESTONE PRODUCTION AND USE

Source: Statistics Canada; Energy, Mines and Resources, Canada.

Comminution power requirement :

crushed product	-	1.5 kWh/t.
ground product*	-	8.5 kWh/t.
ground product -20 µm	-	68 kWh/t.

Estimated comminution power requirement by the limestone industry in 1981 :

crushed product	-	84,000,000 kWh.
ground product	-	14,000,000 kWh.
Total	-	98,000,000 kWh.

* Assuming that the majority of the ground product is for agricultural use.

Background

Limestone is second only to sand and gravel in terms of tonnages produced annually in North America.

About 90% of limestone is sold as crushed stone for such uses as road construction and aggregate for concrete and asphalt. Chemical and metallurgical uses account for 6-7% of shipments. Limestone for these applications is usually required to be high calcium and impurities may be subject to precise specifications. A smaller quantity, about 3% of total limestone production, is marketed in pulverized form for agricultural and filler purposes.

The Production Process

The quarrying and preparation of limestone depends on its intended application.

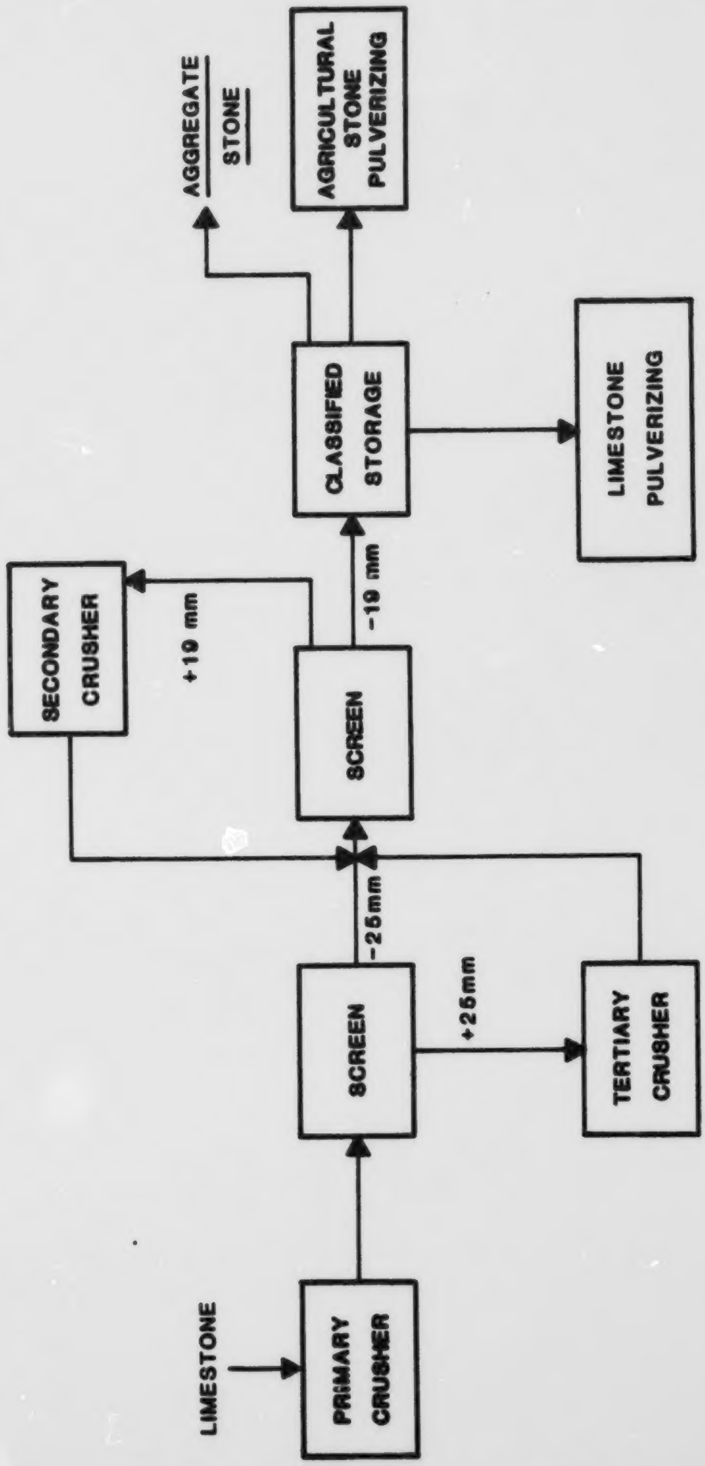
For dimension stone, large, uniform blocks are required. It is almost invariably worked from open pits. Channeling machines are used to make primary cuts for block separation. Once a key block is broken loose, horizontal holes can be drilled beneath adjoining blocks. They are then subdivided into mill blocks and hoisted to the surface. These blocks can be sold as is or further finished by cutting, carving, planing and polishing.

The main use of limestone is as aggregate. The rock is removed by blasting. The type of primary crusher employed depends on the hardness and fracturing qualities of the stone, and particularly on the gradation that is desired in the product. For lime kiln feed, fluxstone and coarse aggregate, jaw or gyratory crushers are necessary. For use as cement kiln feed, impact crushers are preferred because they crush more finely.

The flow sheet on page 74 summarizes a typical production process.

LIMESTONE PROCESS FLOW SHEET

DOMTAR JOLIETTE PLANT


LIMESTONE
PRIMARY CRUSHER
SCREEN
-25mm
+25mm
TERTIARY CRUSHER
SCREEN
+19 mm
SECONDARY CRUSHER
-19 mm
CLASSIFIED STORAGE
AGGREGATE
STONE
AGRICULTURAL STONE PULVERIZING
LIMESTONE PULVERIZING

The Role of Comminution

Crushing, produces a range of aggregate products and prepares material for pulverizing. The size specification of the product determines the extent to which the material is comminuted.

Pulverizing, for agricultural stone and filler grade products, limestone is subjected to grinding. Agricultural grades are relatively coarse; 50% less than 0.25 mm. Filler grades may be as fine as 99.5% passing a 45 μm sieve and an average particle size of 10 μm.

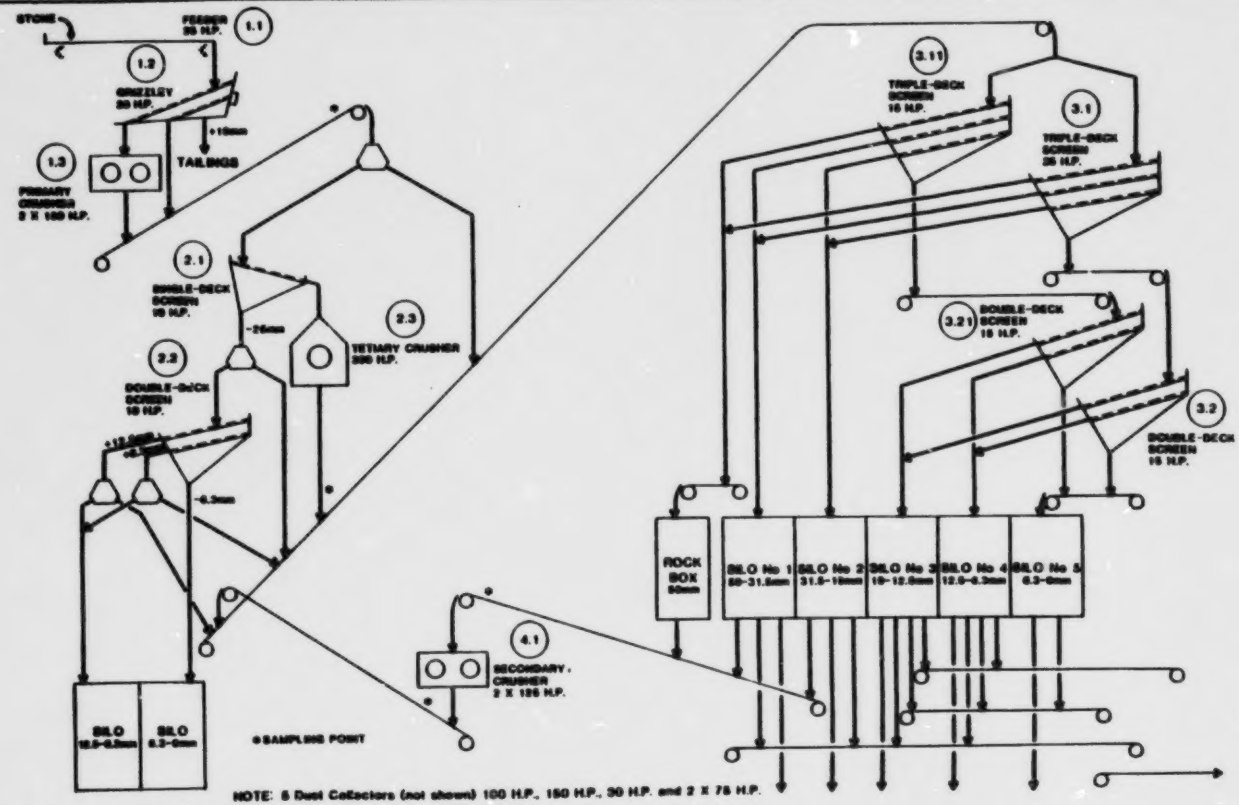
Comminution at the Domtar Plant

The crushing circuit and power levels in kilowatts are given on the diagram on page 76.

The average feed rate to the circuit was estimated at 404 tonnes per hour. The optimum production rate for the mill, if continuously fed, is 680 tonnes per hour.

Grindability. The Hardgrove Index was found to be 66, giving a calculated Bond Index of 9.61 kWh/ton. The tested Bond Index was 8.41 kWh/ton.

The **size distribution** of the primary crusher feed was minus 900 mm, plus 150 mm and mainly minus 450 mm, plus 150 mm.


STONE
FEEDER
35 H.P.
1.1
1.2
GRIZZLEY
20 H.P.
+10mm
TAILINGS
1.3
PRIMARY
CRUSHER
2 X 150 H.P.
2.1
SINGLE-DECK
SCREEN
10 H.P.
-25mm
2.3
TETIARY CRUSHER
300 H.P.
2.2
DOUBLE-DECK
SCREEN
10 H.P.
+12.5mm
+6.3mm
-6.3mm
SILO
12.5-6.3mm
SILO
6.3-0mm
• SAMPLING POINT
4.1
SECONDARY
CRUSHER
2 X 125 H.P.
3.11
TRIPLE-DECK
SCREEN
15 H.P.
3.1
TRIPLE-DECK
SCREEN
25 H.P.
3.21
DOUBLE-DECK
SCREEN
15 H.P.
3.2
DOUBLE-DECK
SCREEN
15 H.P.
ROCK
BOX
50mm
SILO No 1
50-31.5mm
SILO No 2
31.5-19mm
SILO No 3
19-12.5mm
SILO No 4
12.5-6.3mm
SILO No 5
6.3-0mm

NOTE: 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	KW AVG.
1.1	FEEDER	2
1.2	GRIZZLEY	8
1.3	PRIMARY CRUSHER	74
		98
1.4	DUST COLLECTOR	48
2.1	SINGLE-DECK SCREEN	5
2.3	TERTIARY CRUSHER	195
2.4	DUST COLLECTOR	51

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	KW AVG.
3.1	TRIPLE-DECK SCREEN	8
3.11	TRIPLE-DECK SCREEN	5
3.2	DOUBLE-DECK SCREEN	6
3.21	DOUBLE-DECK SCREEN	5
3.3	DUST COLLECTOR (SCREEN)	51
3.4	DUST COLLECTOR (CONVYR)	16
4.1	SECONDARY CRUSHER	54
		33
4.2	DUST COLLECTOR	28

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DATE [illegible]

AGGREGATE CRUSHING & SCREENING
FLOW DIAGRAM

PLANT of PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010

A typical product size distribution for the crushing circuit is given in the table below.

CRUSHING CIRCUIT TYPICAL PRODUCT SIZE DISTRIBUTION	
mm	% Passing
50.0	100
31.5	98.2
19.0	96.7
12.5	62.7
6.3	32.4

Pulverizing Circuits

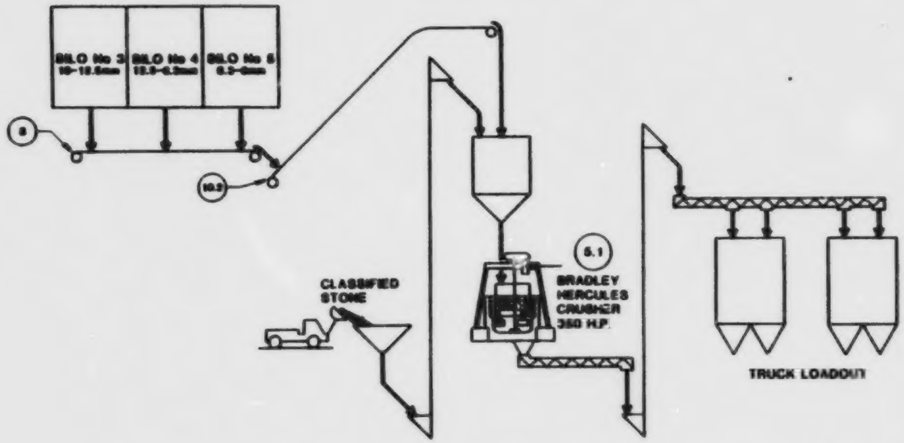
There are two pulverizing processes, one for the relatively coarse agricultural stone, the other for filler products.

The agricultural stone circuit and the power data for the equipment are given in the sketch on page 78. The Bradley Hercules pulverizer was not operating during the study.

The **flowrate** to the mill is 41 t/h, and is normally very steady.

The **size distribution** of feed and product are summarized in the following table.

SIZE DISTRIBUTION % Passing		
mm	FEED Bradley Pulverizer	PRODUCT Agricultural Stone
6.7	100	---
4.75	86	---
3.35	72	100
2.36	58	99
1.18	40	94
0.600	29	80
0.300	24	52
0.150	16	41
0.075	12	---


SILO No 3
19-12.5mm
SILO No 4
12.5-6.3mm
SILO No 5
6.3-0mm
8
10.2
5.1
BRADLEY
HERCULES
CRUSHER
350 H.P.
CLASSIFIED
STONE
TRUCK LOADOUT

NOTE: Dust Collector (not shown) 25 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
5.1	Bradley 6000 Hercules	206
5.2	Dust Collector	9

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LIMESTONE PULVERIZING (SOLPIER)
FLOW DIAGRAM

PLANT of PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q.

PROJECT No: 20010

The filler product circuit and power observations are shown in the sketch on page 80.

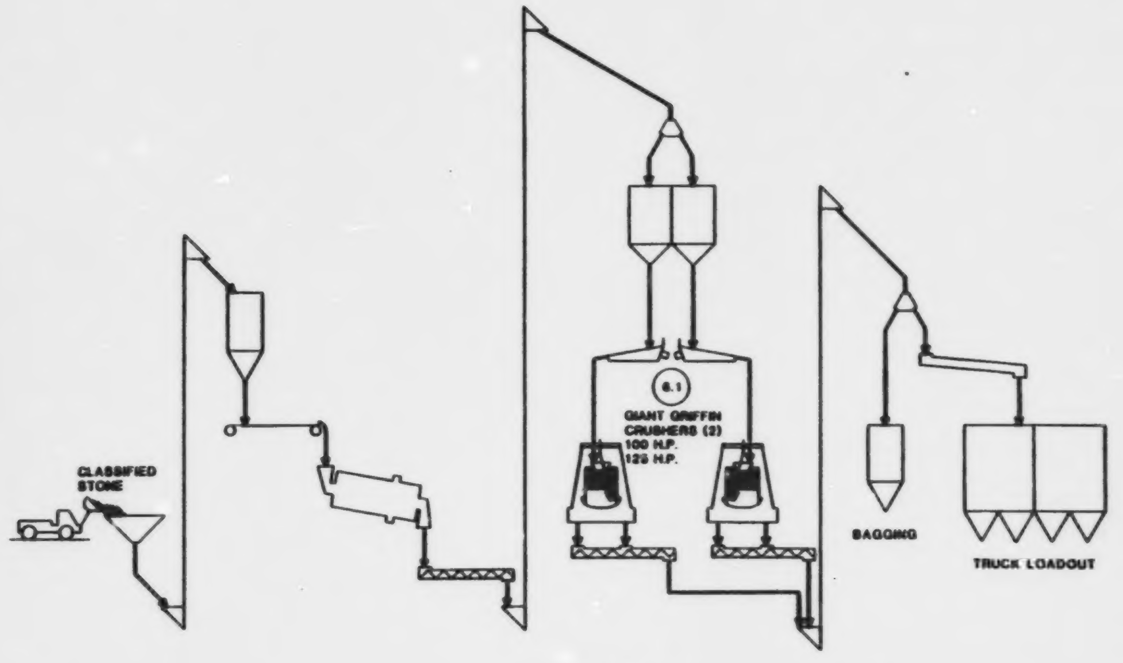
Feedrate to each Griffin Mill was 4.5 t/h.

Particle size distribution of the feed is the same as that for the Bradley Hercules pulverizer.

The product particle size distribution is considerably finer than that of the agricultural stone. The table below summarizes the size distribution from a Sedigraph test.

PARTICLE SIZE DISTRIBUTION
OF LIMESTONE FILLER PRODUCT

µm	%
100	85.5
70	72.0
50	61.5
40	55.5
30	49.0
25	45.5
20	41.5
15	35.5
10	27.5
8	23.5
6	18.0
4	13.0
2	6.5


CLASSIFIED STONE
6.1
GIANT GRIFFIN CRUSHERS (2)
100 H.P.
125 H.P.
BAGGING
TRUCK LOADOUT

NOTE: Dust Collector (not shown) 40 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
6-1	GIANT GRIFFIN - 40" (x2)	72
6-2	DUST COLLECTOR	14

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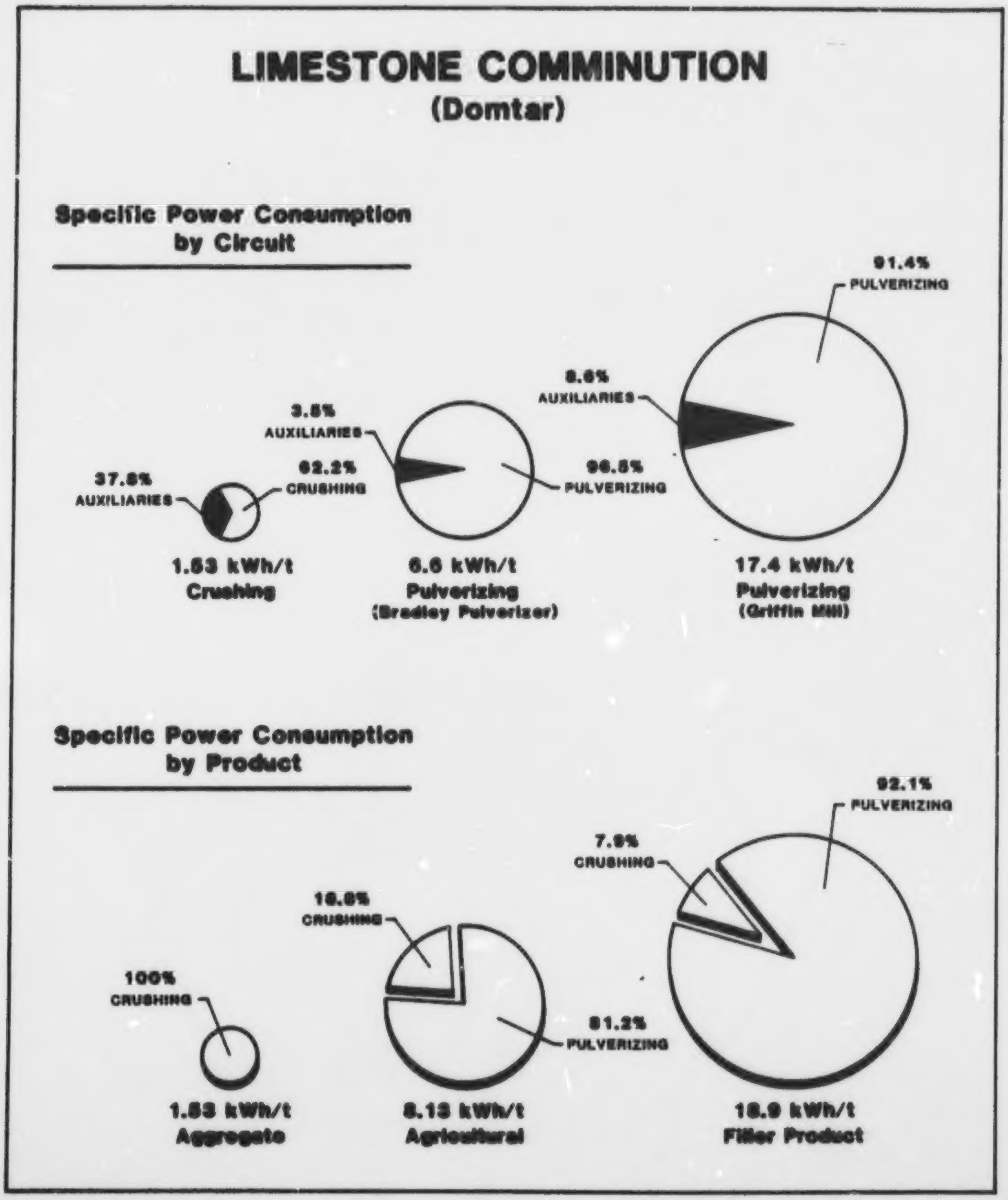
LIMESTONE PULVERIZING (STALCO)
FLOW DIAGRAM

PLANT No. PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No: 20010

Results

The results of the specific power consumption by circuit and the cumulative comminution power consumption by product is given in the diagram below.



Comminution at the Steep Rock Resources Plant

The company operates a quarry at Tatlock, Ontario and a calcite processing plant at Perth. The deposit is unique in its combination of whiteness, high calcium and low magnesium and silica contents.

Three types of products are made:

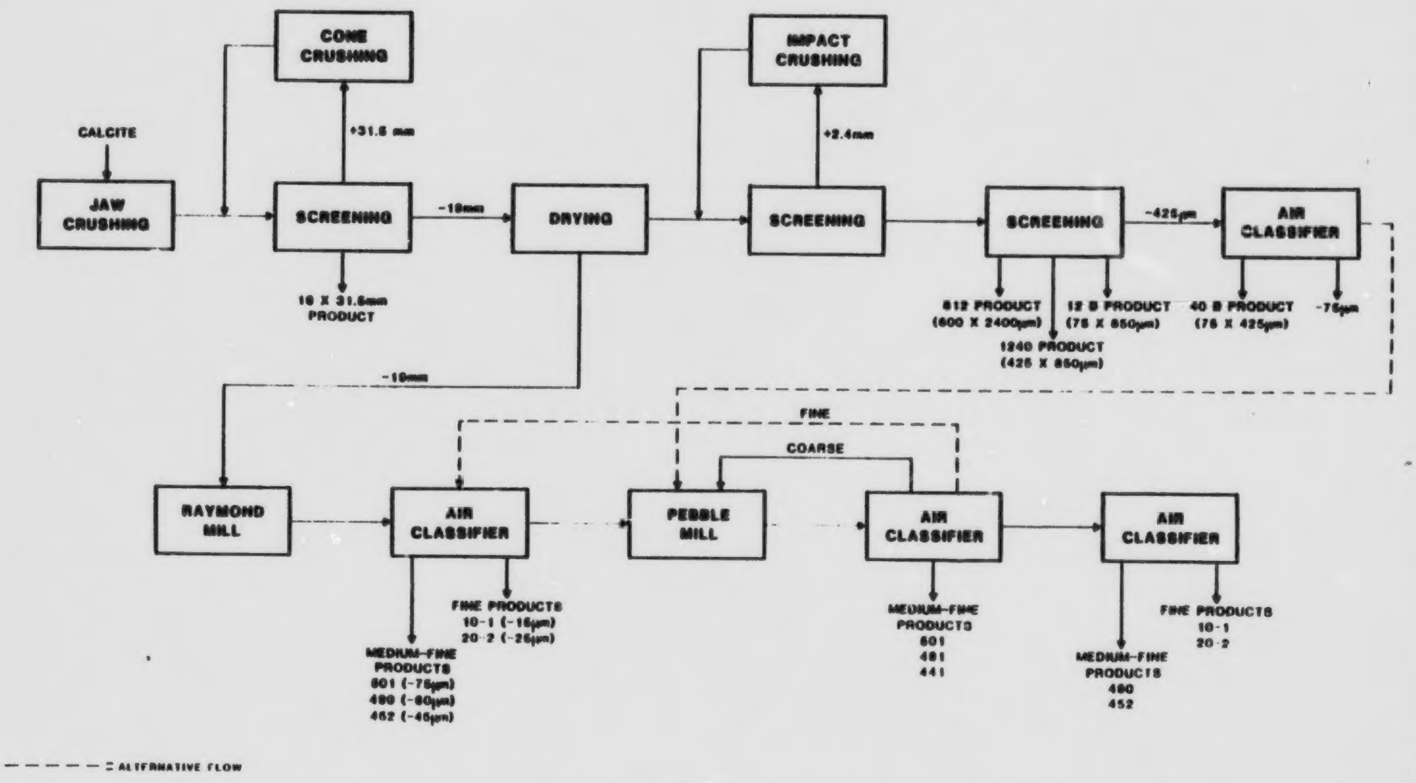
- aggregate stone for white block manufacturing, decorative chips, driveway stone, etc.,
- screened sand grade products for floor tile, stucco mix, cultured marble and animal feed,
- fine and medium-fine ground products for use as fillers in paints, plastics, adhesives and other industrial products.

Process Description

Primary and secondary crushing is done at the quarry where the larger aggregate sizes are screened out and sold. The minus 19 mm product is trucked approximately 40 km to the plant where drying, screening, grinding, and classifying operations are carried out, as shown in the flow sheet overleaf.

CALCITE PROCESS FLOW SHEET

STEEP ROCK CALCITE PERTH, ONTARIO


CALCITE
JAW CRUSHING
CONE CRUSHING
+31.5 mm
SCREENING
19 X 31.5mm PRODUCT
-19mm
DRYING
IMPACT CRUSHING
+2.4mm
SCREENING
SCREENING
812 PRODUCT (600 X 2400µm)
1240 PRODUCT (425 X 850µm)
12 B PRODUCT (75 X 850µm)
-425µm
AIR CLASSIFIER
40 B PRODUCT (75 X 425µm)
-75µm
-19mm
RAYMOND MILL
AIR CLASSIFIER
FINE PRODUCTS 10-1 (-15µm) 20-2 (-25µm)
MEDIUM-FINE PRODUCTS 501 (-75µm) 490 (-60µm) 452 (-45µm)
FINE
COARSE
PEBBLE MILL
AIR CLASSIFIER
MEDIUM-FINE PRODUCTS 501 481 441
AIR CLASSIFIER
MEDIUM-FINE PRODUCTS 490 452
FINE PRODUCTS 10-1 20-2
= ALTERNATIVE FLOW

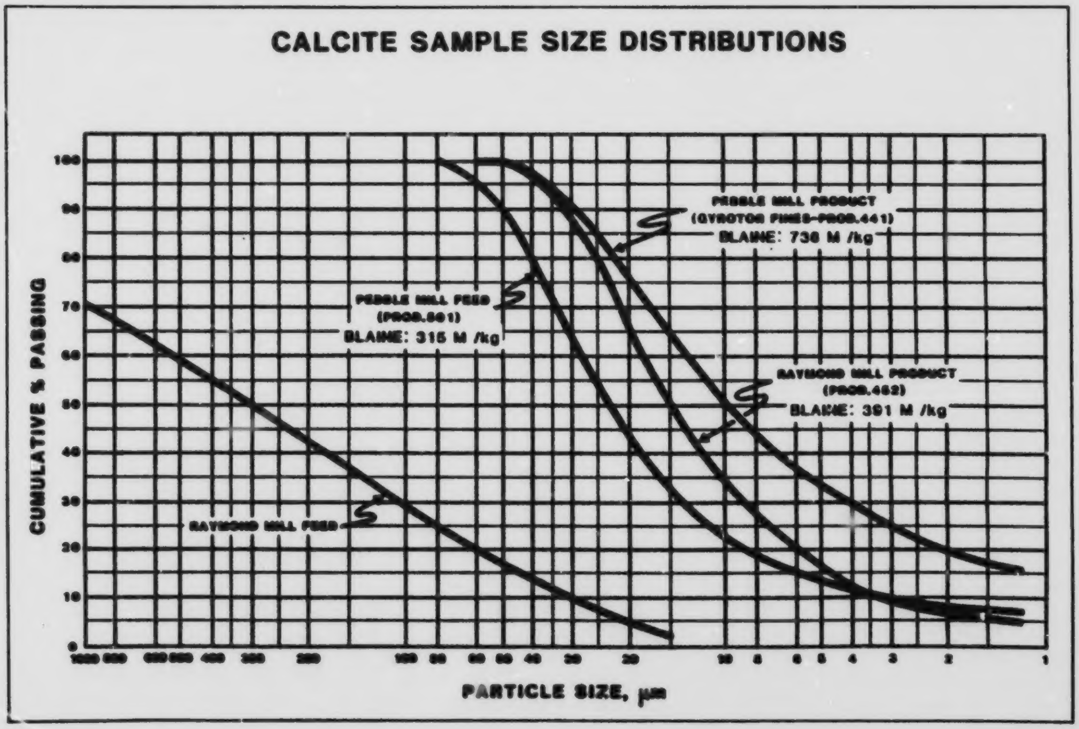
Comminution Processes

The two grinding circuits, outlined in the sketch on page 85, produce the fine and medium-fine products. The Raymond mill is used for the medium-fine products designated 501, 490, and 452. It is standard operating practice to feed the Hardinge pebble mill with the 501 material in processing the fine grind products.

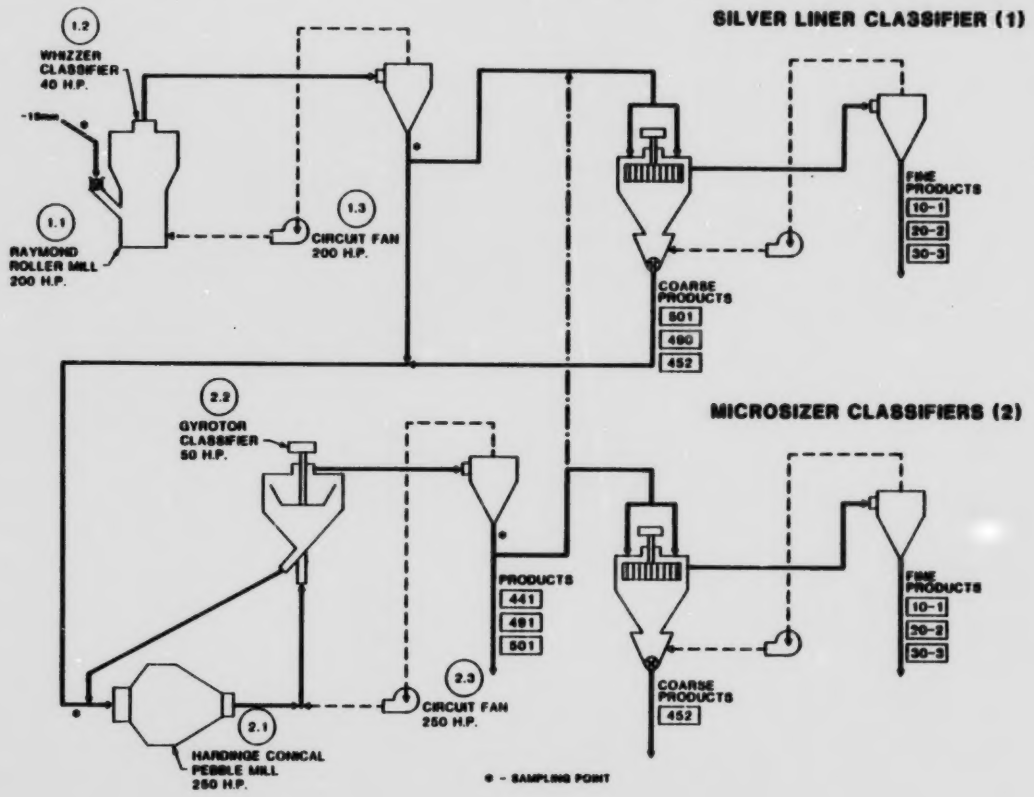
Flowrates for the mill circuits were estimated to be:

- Raymond mill (452 Product) 5.4 t/h
- Pebble mill (441 Product) 5.0 t/h

Particle size of the feed to the mill circuits is summarized on the chart which gives both size distribution and Blaine specific surface area data.



CALCITE SAMPLE SIZE DISTRIBUTIONS


SILVER LINER CLASSIFIER (1)
1.2
WHIZZER CLASSIFIER 40 H.P.
-19mm
1.1
RAYMOND ROLLER MILL 200 H.P.
1.3
CIRCUIT FAN 200 H.P.
FINE PRODUCTS
10-1
20-2
30-3
COARSE PRODUCTS
501
490
452
MICROSIZER CLASSIFIERS (2)
2.2
GYROTOR CLASSIFIER 50 H.P.
PRODUCTS
441
491
501
2.3
CIRCUIT FAN 250 H.P.
2.1
HARDINGE CONICAL PEBBLE MILL 250 H.P.
FINE PRODUCTS
10-1
20-2
30-3
COARSE PRODUCTS
452
● - SAMPLING POINT

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
1.1	RAYMOND ROLLER MILL - 6669	140
1.2	WHIZZER CLASSIFIER	14
1.3	CIRCUIT FAN	76
2.1	HARDINGE CONICAL PEBBLE MILL - 10' x 84"	112
2.2	GYROTOR CLASSIFIER	15
2.3	CIRCUIT FAN	112

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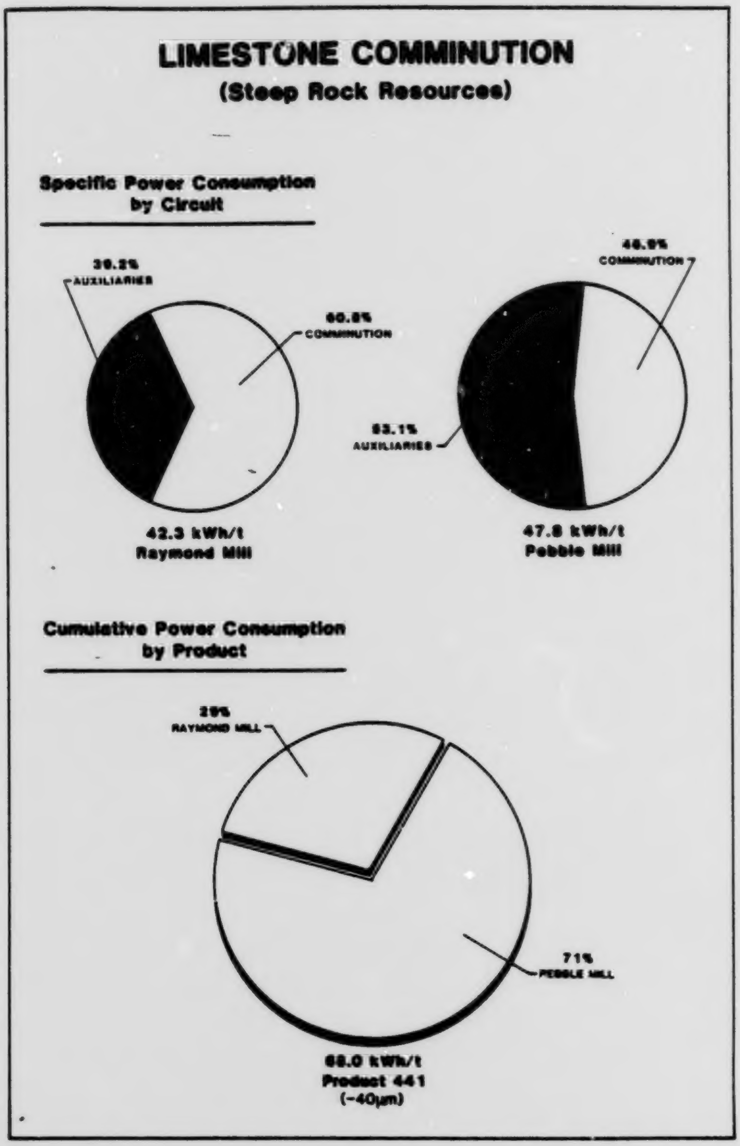
CALCITE GRINDING
RAYMOND AND PEBBLE MILL CIRCUITS
FLOW DIAGRAM

PLANT N° ______

PROJECT No. 20010

The power consumption results for the circuits which are shown in the pie diagrams indicate that the mills have relatively similar specific consumptions.



The reported data does not include consumption for crushing and drying. Experience has shown this consumption to have minimal effect on product energy.

Conclusions

Most of the product volume in the industry is low energy crushed stone.

The Steep Rock plant has very up-to-date technology, especially in the area of classification.

Recommendation

The efficiency of the industry and low overall power consumption suggests that this is not a high priority mineral for further study.

PROCEDE Planilex R PROCESS
MONTREAL QUEBEC

MICA

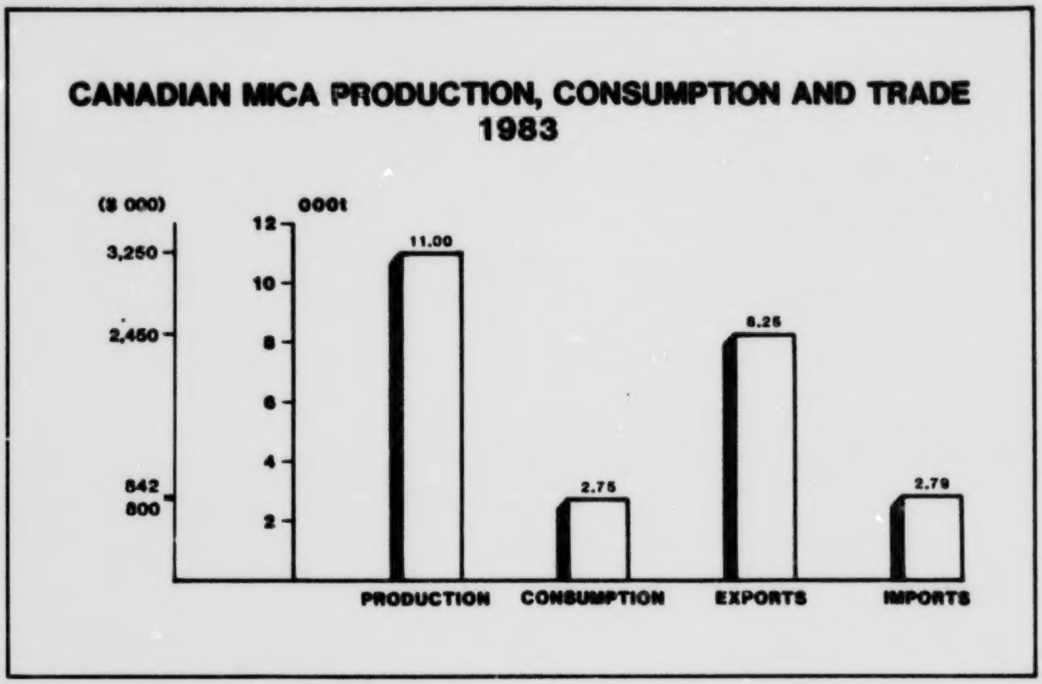
Participating Company

MARIETTA RESOURCES INTERNATIONAL, LTD.

Plant Location

Boucherville, Quebec

Mica: High specific power consumption - low production volume


CANADIAN MICA PRODUCTION, CONSUMPTION AND TRADE 1983

Source: Canadian Mining Journal, February 1984.
Statistics Canada, Energy, Mines and Resources, Canada.

Specific comminution power consumption by product : **coarse - 85 kWh/t.**
fine - 573 kWh/t.

Estimated industry power consumption in comminution for 1983 : **2,950,000 kWh.**

Background

The only company producing mica in Canada is Marietta Resources International Ltd. (MRI) with the participation of Société Minéralurgique Laviolette Inc. The company mines phlogopite mica at the Bédard mine near Parent, Quebec.

Marietta Resources International Ltd. (MRI) has been in operation commercially since 1976 and is currently at a production level of between 10,000 and 12,000 tonnes annually.

The Bédard deposit is estimated to be 30 million tons of 85-95 percent pure ore.

Mining is done by open pit with a recovery rate of seventy-five percent.

Koisumi Group Canada Ltd. has indicated interest in developing a source of muscovite mica near Kaladar, Ontario. Some materials have been sent to Japan to develop processing techniques for a material suitable for the plastic industry.

The United States is the major producer with 63% of world output. Canada is fourth with 4%.

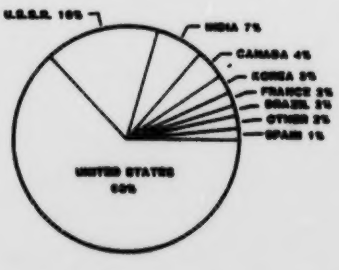
MAJOR WORLD MICA PRODUCERS

ALL FORMS (Ground, Flake & Sheet)
(tonnes)

COUNTRY	1981 (prelim.)	1982 (est.)
UNITED STATES	226,800	183;250
U.S.S.R.	47,170	48,080
INDIA	40,220	21,550
CANADA	11,122	10,079
REPUBLIC OF KOREA	10,000	9,990
FRANCE	6,800	6,490
SPAIN	5,000	3,300
BRAZIL	4,500	4,500
OTHER	10,120	6,160
TOTAL	361,742	293,399

SOURCE: U.S. Bureau of Mines

BREAKDOWN OF WORLD PRODUCTION BY COUNTRY (1982 est.)



Products and Uses

MRI classifies its suzorite mica as coarse (Z), fine beneficiated (S) and ultra fine (FE). They market about 20 different blends, based on purity, degree of fineness and aspect ratio *.

Typical uses are in;

- thermoplastics, thermosets, and glass and phosphate bonded mica (to reinforce and stiffen),
- tape joint compound, cement board and pipe, asphaltic coatings, brake lining and thermal insulation (to replace asbestos),
- oil well drilling muds, radiation sealants, coatings, lining and plastics (to reduce permeability),
- rubber mold release, fire extinguishers, and asphalt roofing (to lubricate, prevent caulking and sticking).

---

* Average diameter of a flake divided by its thickness.

The major physical and chemical properties of suzorite mica are:

PHYSICAL PROPERTIES	
Color	Amber brown
Shape	Thin flakes
Particle Nominal Diameter	20 microns to 0.64cm (0.25 in), depending on grade.
Particle Thickness	0.5 to 300 microns, depending on grade.
Bulk Density (Scott Volumeter)	145-640kg/m^3 (9-40 pcf), depending on grade
Specific Gravity	2.9
Hardness - Moh's	2.5 - 3.0
Ph (of aqueous suspension)	7.5
Water Solubility	Virtually insoluble

CHEMICAL COMPOSITION	
COMPONENTS	% BY WEIGHT
SiO_2	40.7
Al_2O_3	15.8
MgO	20.6
K_2O	10.0
Total Fe (as FeO)	8.9
F	2.2
H_2O+	3.0
BaO	0.5
Na_2O	0.5
TiO_2	0.4
Cr_2O_3	0.2
NiO	0.3
V_2O_5	Less 0.1
S and P	Less 0.1

The Production Process

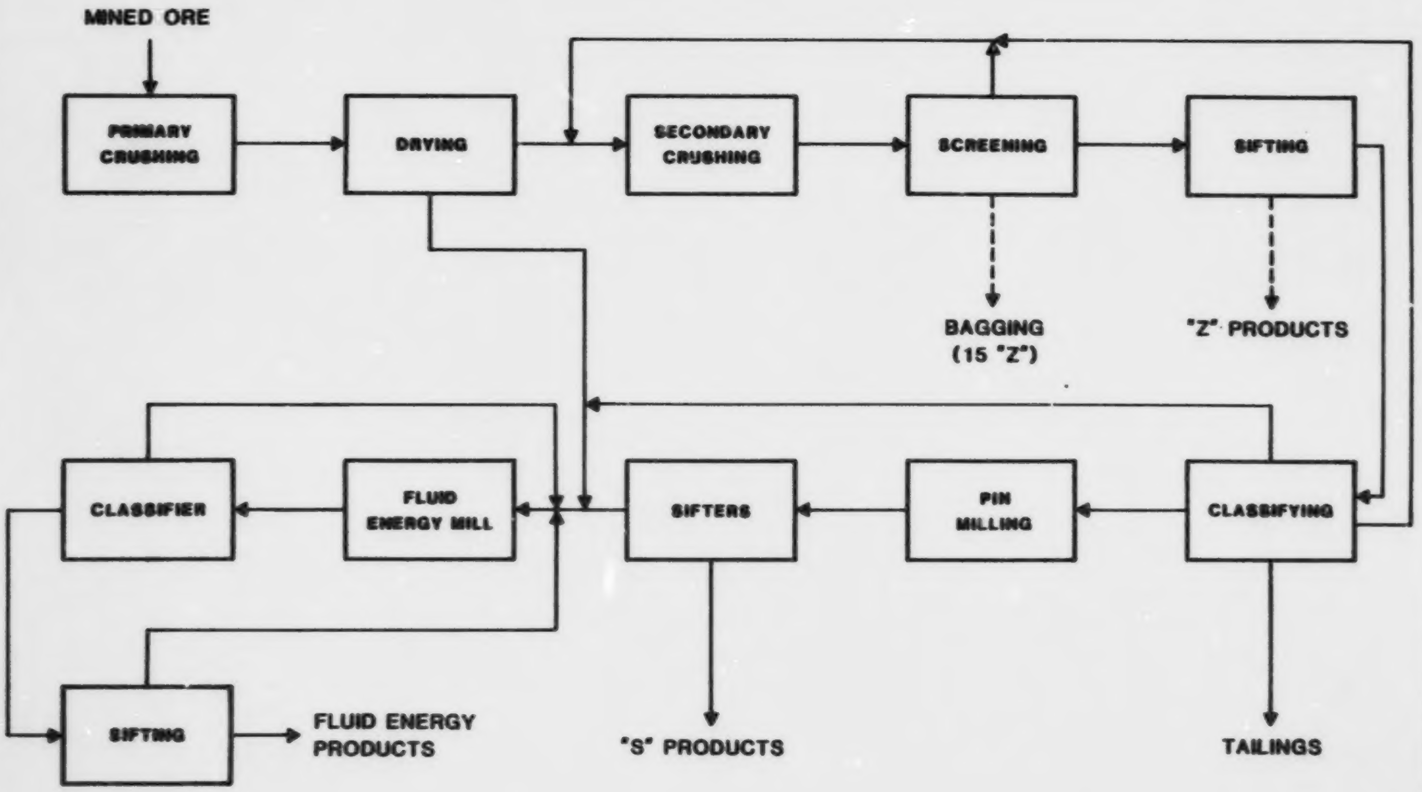
An overview of the production process is shown on the flow sheet overleaf.

There are three distinct phases, each defined by its product; Z, S and FE.

Comminution in the true sense is a limited operation except in the primary crushing stage, which receives the mixed ore from the stockpile. Elsewhere, the impact crushers, pin mill and fluid energy mill are used to delaminate the flakes.

MICA PROCESS FLOW SHEET

MARIETTA RESOURCES LTD., BOUCHERVILLE, QUEBEC


MINED ORE
PRIMARY CRUSHING
DRYING
SECONDARY CRUSHING
SCREENING
SIFTING
BAGGING (15 "Z")
"Z" PRODUCTS
CLASSIFIER
FLUID ENERGY MILL
SIFTERS
PIN MILLING
CLASSIFYING
SIFTING
FLUID ENERGY PRODUCTS
"S" PRODUCTS
TAILINGS

The Role of Comminution

There are three comminution steps in mica production:

Crushing, where the mined ore is reduced to a suitable size for the pin mill feed or for bagging as "Z" products.

Pin Milling, where material is further reduced in size to give a ground product ("S") or feed for the fluid energy mill.

Fluid Energy Milling, where raw mica and dust are further processed to produce products, 40-95% passing 45 μm.

Comminution at the Boucherville plant

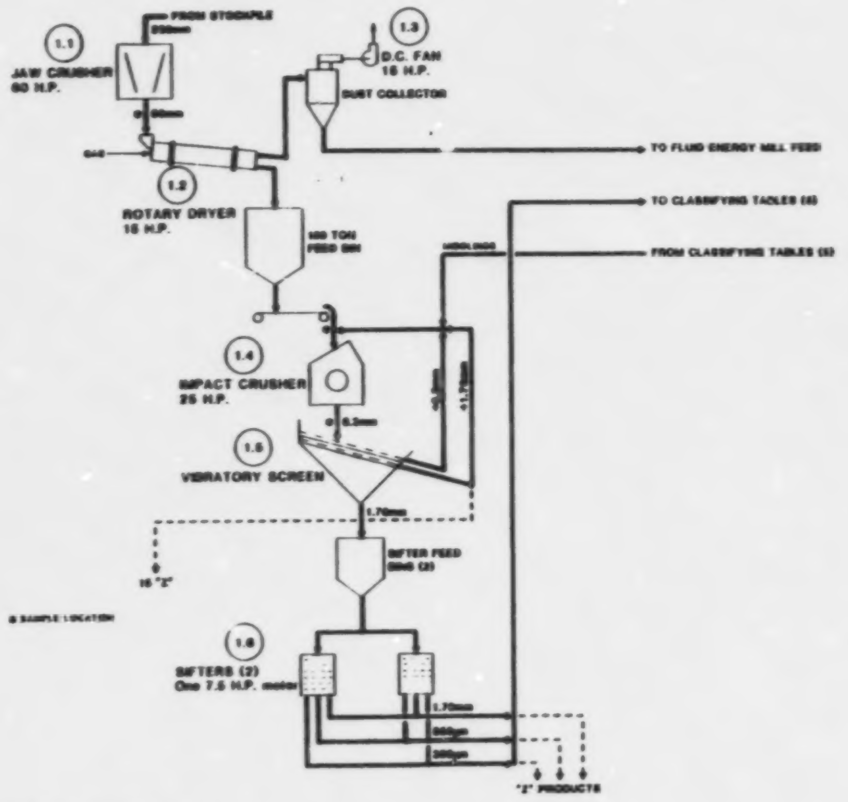
Crushing

The crushing circuit is shown schematically on page 94. Power levels are summarized on the flow diagram.

The **flowrate** averages 6 tonnes per hour of dry ore, but fluctuates depending on ore moisture content.

As shown, there are two crushing stages reducing the initial 230 mm feed to 50 mm then to 6.3 mm.

There is a limited production of coarse gangue contaminated material. But, primarily the material from the crushers is the feed for the "Z" product sifters.


FROM STOCKPILE
250mm
1.1
JAW CRUSHER
60 H.P.
Ø 60mm
GAS
1.2
ROTARY DRYER
15 H.P.
1.3
D.C. FAN
15 H.P.
DUST COLLECTOR
TO FLUID ENERGY MILL FEED
TO CLASSIFYING TABLES (8)
FROM CLASSIFYING TABLES (8)
MIDDLINGS
100 TON
FEED BIN
1.4
IMPACT CRUSHER
25 H.P.
Ø 6.2mm
1.5
VIBRATORY SCREEN
1.70mm
TO "Z"
SIFTER FEED
BINS (2)
Ø SAMPLE LOCATION
1.6
SIFTERS (2)
One 7.5 H.P. motor
1.70mm
850μm
300μm
"Z" PRODUCTS

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
1.1	Jaw Crusher	7.0
1.2	Rotary Dryer	3.7
1.3	Dryer D.C. Fan	9.0
1.4	Impact Crusher	6.7
1.5	Vibratory Screen (Air Operated)	-
1.6	'Z' Product Sifters	1.3

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN OFJ
DATE 20/01/84
CHECKED DCS
DATE 29/08/84

CRUSHING CIRCUIT

PLANT OF MARIETTA RESOURCES LTD.
[illegible]

PROJECT No: 20010

Milling

The "Z" product feed is classified and only the fine fraction becomes feed for the pin mill, as shown on the circuit flow diagram.

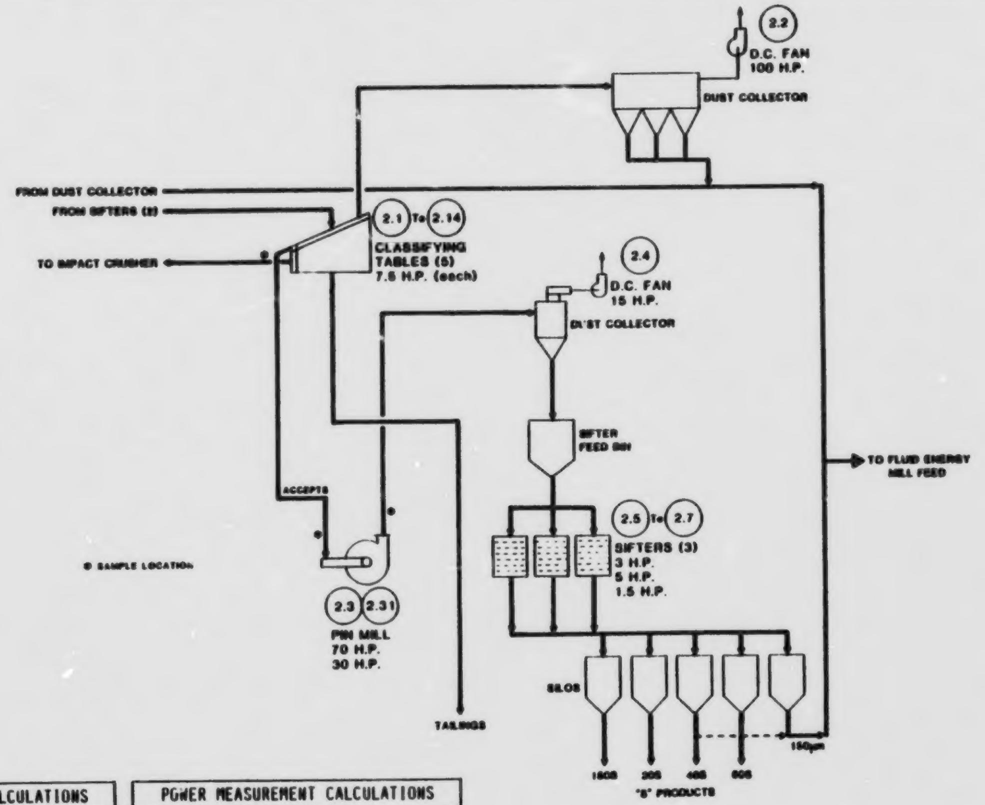
Flowrate to the circuit obtained from plant records was 1.32 t/h. The pin mill product flows through a dust collector prior to entering the sifters which produce "S" products and feed for the fluid energy mill circuit.

Particle size distributions of the feed and typical product are shown in the table below.

SUZORITE MICA SIZE DISTRIBUTION % Passing		
Size	15 "Z" PRODUCT	20 "S" PRODUCT
6.3 mm	100	
4.75	84.1	
2.36	23.5	100
1.18	1.7	33.3
600 µm	0.7	2.4
300	0.5	1.6
150	0.3	1.0

The **grindability** of mica was determined by the Hardgrove method. The Bond index, which could not be determined experimentally because of the flaky nature of the material, was calculated from the Hardgrove results.

PRODUCT	GRINDABILITY	
	HARDGROVE	BOND INDEX
15 "Z"	16	35 kWh/T
20 "S"	13	42 kWh/T


2.2
D.C. FAN
100 H.P.
DUST COLLECTOR
FROM DUST COLLECTOR
FROM SIFTERS (2)
TO IMPACT CRUSHER
2.1 To 2.14
CLASSIFYING
TABLES (5)
7.5 H.P. (each)
2.4
D.C. FAN
15 H.P.
DUST COLLECTOR
SIFTER
FEED BIN
TO FLUID ENERGY
MILL FEED
ACCEPTS
2.5 To 2.7
SIFTERS (3)
3 H.P.
5 H.P.
1.5 H.P.
● SAMPLE LOCATION
2.3 2.31
PIN MILL
70 H.P.
30 H.P.
SILOS
TAILINGS
150μm
150S
20S
40S
60S
"S" PRODUCTS

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
2-3	PIN MILL (OPPOSITE DIRECTION)	26.0
2.31	PIN MILL (OPPOSITE DIRECTION)	6.3
2.40	PIN MILL D.C. FAN	7.2
2.50	SIFTERS #3	1.8
2.60	SIFTERS #6	1.8
2.70	SIFTERS - 150S	---

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
2.1	CLASSIFYING TABLE #1	3.6
2.11	CLASSIFYING TABLE #2	3.6
2.12	CLASSIFYING TABLE #3	3.7
2.13	CLASSIFYING TABLE #4	2.4
2.14	CLASSIFYING TABLE #5	3.5
2.2	CLASSIFYING TABLES D.C. FANS	45.2
2.3	PIN MILL (SAME DIRECTION)	16.9
2.31	PIN MILL (SAME DIRECTION)	3.4

CANADA CEMENT LAFARGE LTD.
MONTREAL

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PIN MILLING CIRCUIT

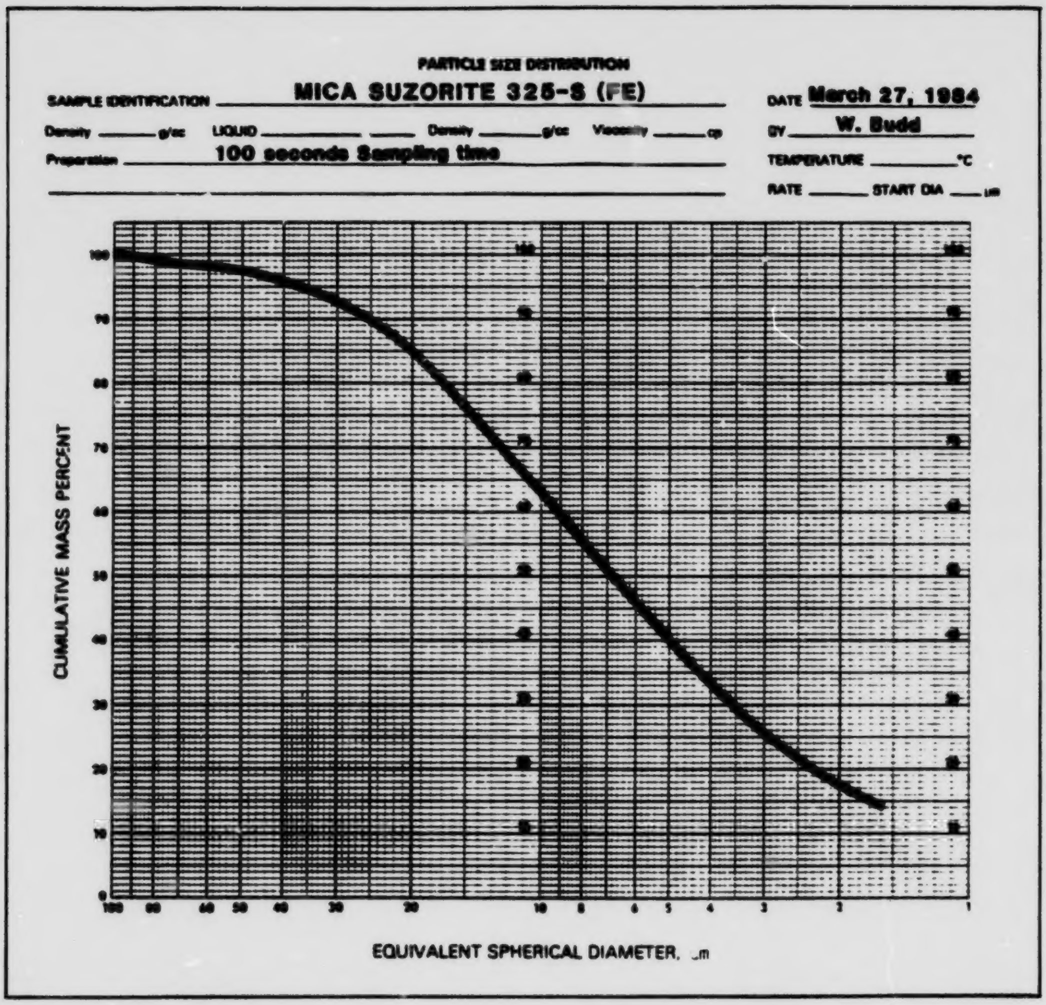
PLANT Nº MARIETTA RESOURCES LTD.
BOUCHERVILLE, QUEBEC

PROJECT No. 20010

The Fluid Energy Mill is used for ultra fine products: 40 to 95 percent passing 45 µm. A schematic of the circuit is on page 98.

Flowrate to the mill, as determined from plant records, was 0.68 t/h.

Particle size distribution. As previously mentioned, the "S" product, whose size distribution is given in the table on page 95, is feed for the FE mill. The size distribution of the product is shown in the Sedigraph trace below.



PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION MICA SUZORITE 325-S (FE)

DATE March 27, 1984

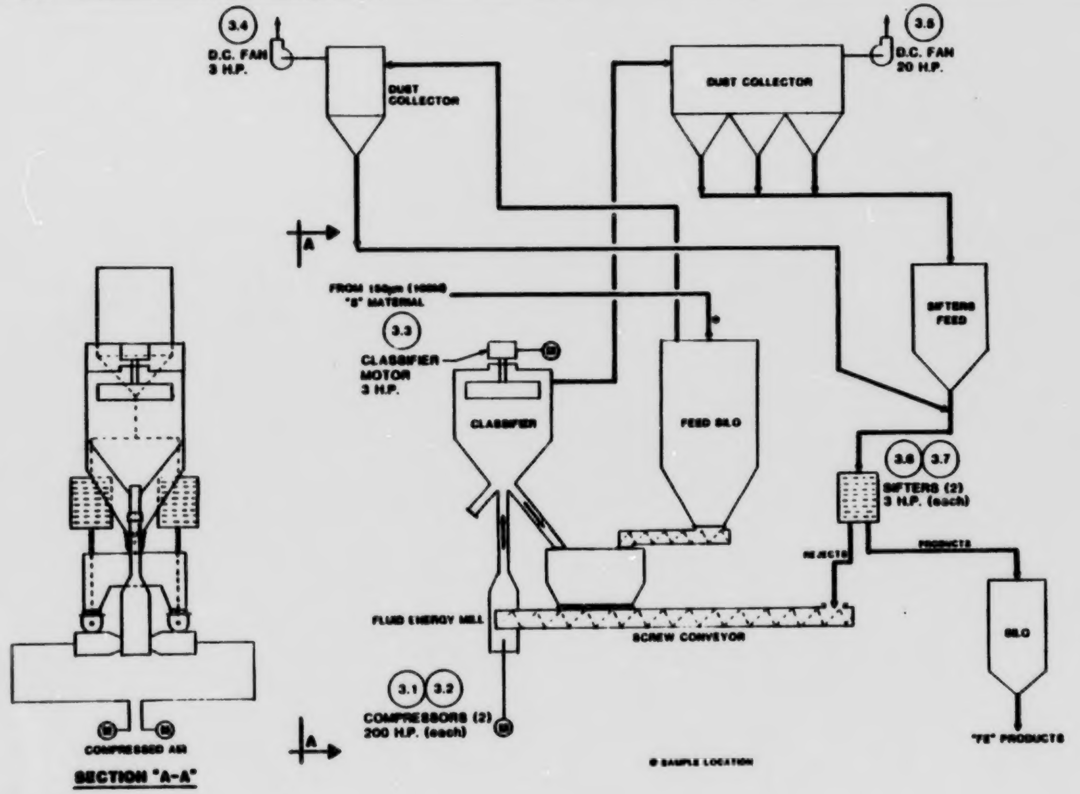
Density ____ g/cc LIQUID ________ ____ Density ____ g/cc Viscosity ____ cp

BY W. Budd

Preparation 100 seconds Sampling time

TEMPERATURE ____ °C

RATE ____ START DIA ____ µm


3.4
D.C. FAN
3 H.P.
DUST COLLECTOR
DUST COLLECTOR
3.5
D.C. FAN
20 H.P.
A
FROM 150µm (100M)
"S" MATERIAL
SIFTERS FEED
3.3
CLASSIFIER
MOTOR
3 H.P.
CLASSIFIER
FEED SILO
3.6
3.7
SIFTERS (2)
3 H.P. (each)
REJECTS
PRODUCTS
FLUID ENERGY MILL
SCREW CONVEYOR
SILO
3.1
3.2
COMPRESSORS (2)
200 H.P. (each)
A
"FE" PRODUCTS
SAMPLE LOCATION
COMPRESSED AIR

SECTION "A-A"

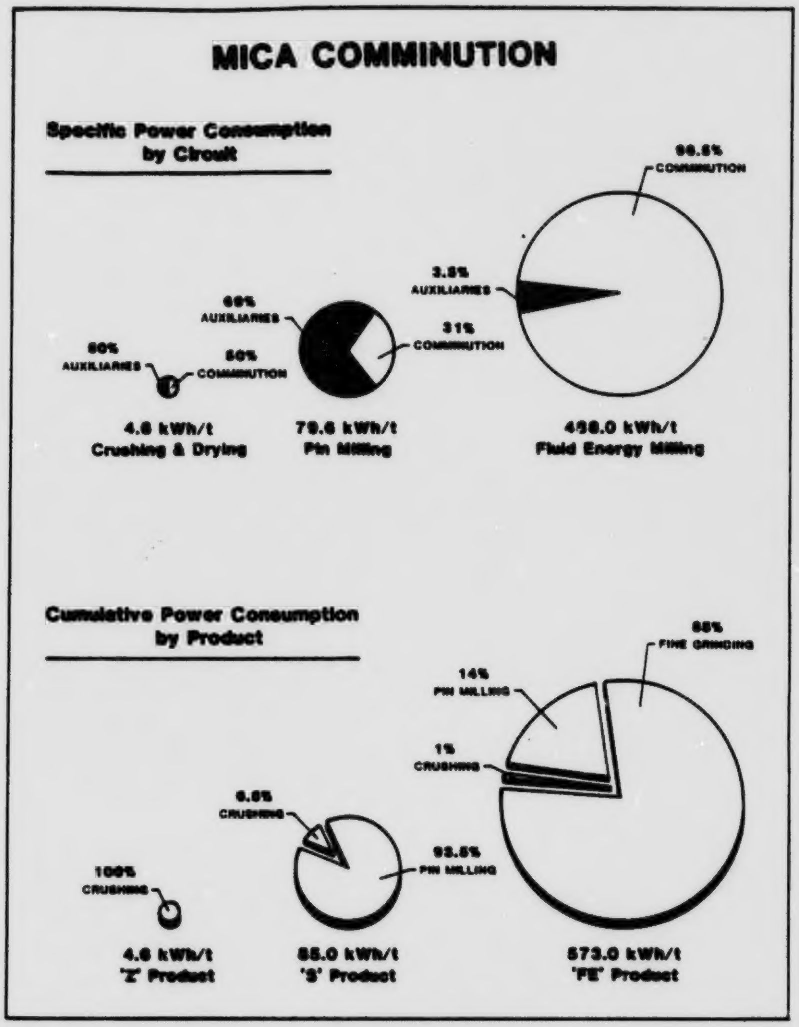
POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
3.1	Fluid Energy Mill Compressor #1	147.5
3.2	Fluid Energy Mill Compressor #2	172.8
3.3	Classifier Motor	1.5
3.4	Fluid Energy Mill Small D.C. Fan	3.2
3.5	Fluid Energy Mill Large D.C. Fan	6.0
3.6	Fluid Energy Sifter #9	0.7
3.7	Fluid Energy Sifter #10	0.8

PLANT AIR SUPPLY		
No.	EQUIPMENT	kW AVG.
1	Plant/D.C. Air Comp.	40.2
1	Plant/D.C. Air Comp.	42.5

CANADA CEMENT LAFARGE LTD. MONTREAL		
DRAWN QFJ DATE 20/01/84	FLUID ENERGY MILL CIRCUIT	PLANT Nº MARIETTA RESOURCES LTD BOUCHERVILLE, QUEBEC
CHECKED DCS DATE 20/09/84		PROJECT No: 20010

Results

The specific power consumption in the crushing and milling circuits are summarized below.



The high specific power consumption is related both to the low Hardgrove index, which indicates that it is the most difficult to grind of the ten minerals studied, and the fineness of the "FE" product. Reported product consumptions also include an additional 62.2 kWh/t for supplying compressed air to dust collectors, etc., determined from electrical measurements and an estimated average plant production rate.

Conclusions

Conclusions of the study were found to be:

- the production of fine products, below 95 µm, is very energy intensive;
- the plant air and dust control systems are significant power consumers;
- energy savings may be achieved by using other types of milling equipment;
- better classification of fine product could possibly achieve increased production;
- that mica is extremely abrasive, requiring specialized materials and methods of milling.

Recommendations

Recommendations to the industry to achieve energy savings are:

- investigate other types of mills for delamination and fine grinding;
- test other types of materials for their abrasiveness towards mica;
- test other types of classifying equipment to reduce the recirculation load;
- due to the low bulk density of the beneficiated mica, have fine grinding units located near market centers.

[illegible]
PROCÉDÉ Pladex ® PROCESS
MONTREAL, QUEBEC

NEPHELINE SYENITE

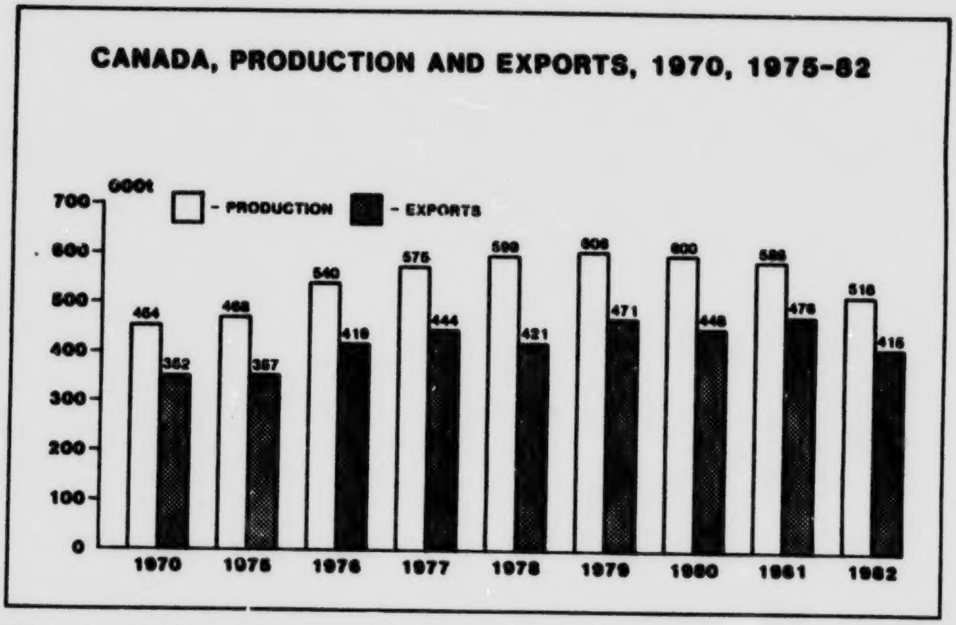
Participating Company

INTERNATIONAL MINERALS AND CHEMICAL CORPORATION

Plant Location

Blue Mountain, Ontario

Nepheline Syenite: High specific energy consumption for fine products, small volume



CANADA, PRODUCTION AND EXPORTS, 1970, 1975-82

Source: Canadian Minerals Yearbook 1982, EMR Canada.

Average comminution power requirement : *34.5 kWh/t.

Estimated average annual comminution power requirement by the nepheline syenite industry : 20,000,000 kWh.

Background

Canadian nepheline syenite products are manufactured by two companies operating quarries and mills in Ontario.

Canada exports about three-quarters of its production with 85% of exports going to the United States.

---

* 70% glass grades, 16% ceramic grades, 14% fillers.

Products and Uses

NEPHELINE SYENITE PRODUCTS AND USES
(IMC Product Range)

"A" GRADE PRODUCTS (Fe_2O_3 = 0.08%)	PARTICLE SIZE	USAGE
1. Apex 700	90% minus 10 µm 60% minus 5 µm 40% minus 3 µm	fillers
2. Apex 400	90% minus 20 µm 60% minus 10 µm 38% minus 5 µm	
3. Peak	96% minus 45 µm	ceramics
4. Crest	95% minus 45 µm	
5. C-3	92% minus 45 µm	
6. C-4	88% minus 45 µm	
7. Super 40 "A" Grade	100% minus 425 µm	clear glass manufacture
8. 40 Mesh "A" Grade	97% minus 425 µm	
9. 40 Mesh High Fines "A" Grade	95% minus 425 µm 23% minus 75 µm	
10. 30 Mesh "A" Grade Summit "F"	100% minus 600 µm	
11. 30 Mesh "A" Grade Summit "W"	100% minus 600 µm	
"B" GRADE PRODUCTS (Fe_2O_3 = 0.30%)		
1. Super 40 Mesh "B" Grade	100% minus 425 µm	glass containers
2. 30 Mesh "B" Grade Ridge	99% minus 600 µm	
3. 30 Mesh High Fines "B" Grade	100% minus 600 µm 31% minus 75 µm	
CRUDE		
1. Half Plus	100% Minus 50 mm Plus 25 mm	rockwool

When used for glassmaking, nepheline syenite has a typical size distribution between 600 and 75 µm, an alumina content in excess of 22%, an alkali content of about 14%, and an iron oxide content of less than 0.08%.

Used as a flux in ceramics, a fineness of less than 75 µm is required, as well as the aforementioned chemical specification.

As filler, the important qualities are particle size of less than 20 µm and high dry brightness.

A typical chemical analysis is as follows.

Component	%
SiO_2	60.1
Al_2O_3	23.3
Fe_2O_3	0.07
CaO	0.7
MgO	0.1
Na_2O	10.1
K_2O	4.9
LOI	0.65

The Production Process

A typical process flow sheet is shown overleaf.

The nepheline syenite process deals mainly with size reduction and control of iron content. Control of alumina and alkalies is by selective mining. Ore received at the plant has been selectively quarried and blended, based on information from drill core evaluation.

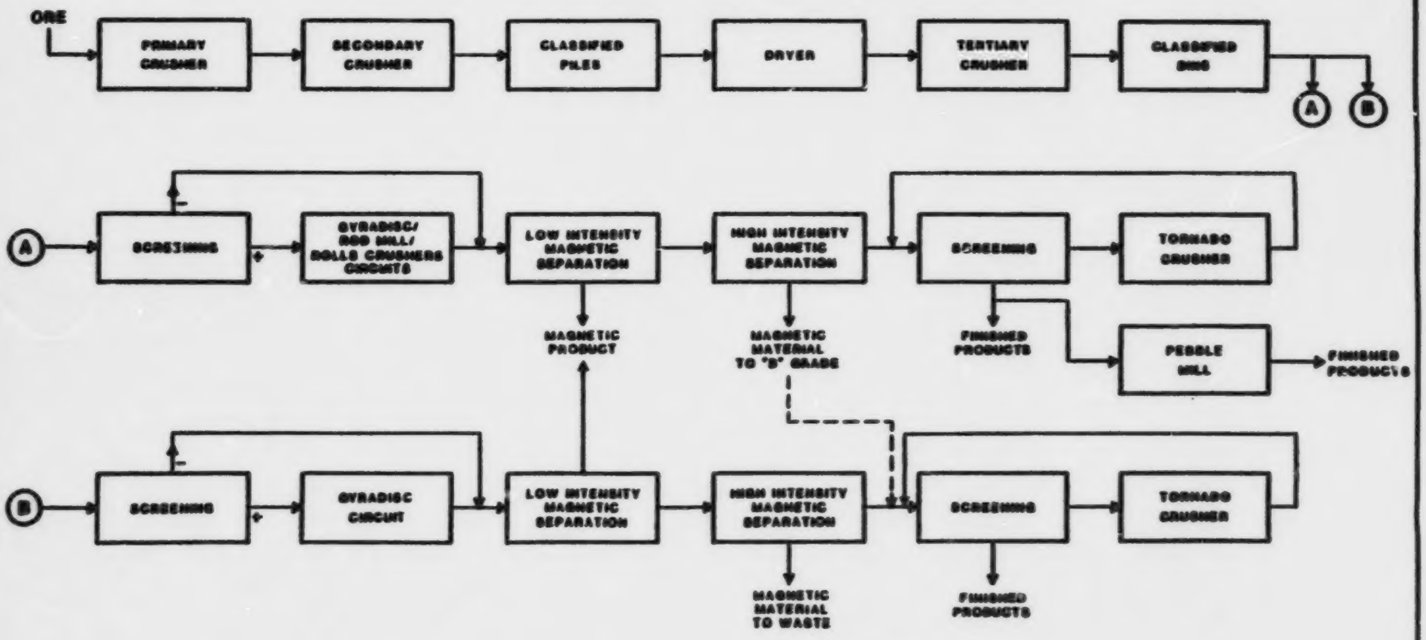
Ore is reduced in jaw and cone crushers before being dried. The dried ore is further reduced in impact or cone crushers. The material is then screened and the oversize further reduced by roll and gyradisc crushers and by rod mill grinding.

Magnetite and iron-bearing minerals are removed, using low and high intensity magnetic separators. Beneficiation also occurs by wasting dust from process dust collectors in the crushing circuits.

Final screening produces various products for the glass industry.

Ceramic and filler products are ground in pebble mills operating in closed circuit with air classifiers.

NEPHELINE SYENITE
SUMMARIZED PROCESS FLOW SHEET
IMC – BLUE MOUNTAIN PLANT, ONTARIO


ORE
PRIMARY CRUSHER
SECONDARY CRUSHER
CLASSIFIED PILES
DRYER
TERTIARY CRUSHER
CLASSIFIED BINS
A
B
A
SCREENING
+
−
GYRADISC/ ROD MILL/ ROLLS CRUSHERS CIRCUITS
LOW INTENSITY MAGNETIC SEPARATION
HIGH INTENSITY MAGNETIC SEPARATION
SCREENING
TORNADO CRUSHER
MAGNETIC PRODUCT
MAGNETIC MATERIAL TO "D" GRADE
FINISHED PRODUCTS
PEBBLE MILL
FINISHED PRODUCTS
B
SCREENING
+
−
GYRADISC CIRCUIT
LOW INTENSITY MAGNETIC SEPARATION
HIGH INTENSITY MAGNETIC SEPARATION
SCREENING
TORNADO CRUSHER
MAGNETIC MATERIAL TO WASTE
FINISHED PRODUCTS

The Role of Comminution

There are three comminution steps in nepheline syenite processing.

Crushing, where the ore is reduced to a size suitable for feeding to coarse grinding. Drying also takes place at this stage.

Exolon* Feed Preparation, where crushed ore is further reduced to 600 µm as feed for the magnetic separators.

Fine grinding, where beneficiated material is ground to about 95% minus 45 µm. A special air sifter classifier operates in closed circuit with the pebble mill and produces 90% minus 10 and 20 µm products.

Comminution at the Blue Mountain Plant

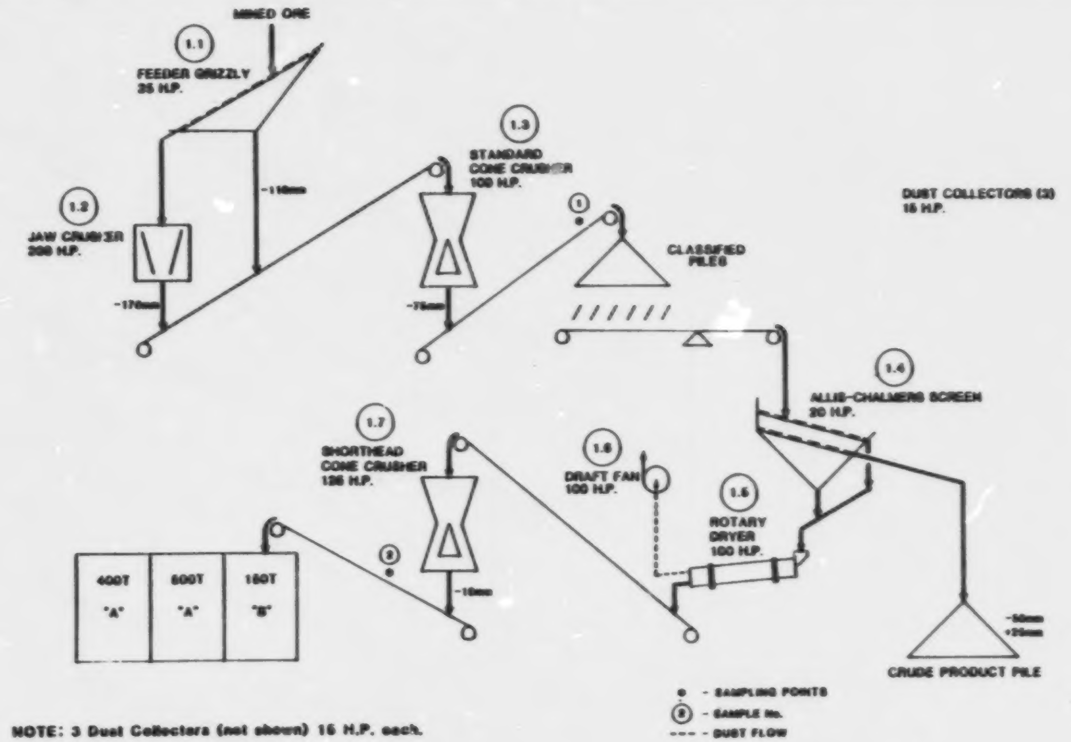
The Crushing Circuit

The circuit is shown schematically on page 106. Rated power (HP) and average demand (kW) in operation are summarized on the sketch.

The circuit is made up of two sections: one involving primary and secondary crushers, the other involving dryer and tertiary crusher. **Flowrate** through primary and secondary crushing was 190 t/h, while drying and tertiary crushing flowrate was 91 t/h.

Primary crusher feed **particle size distribution** was estimated to be -900 +50 mm with most of the material -450 +150 mm. Primary crusher product was estimated to be -175 mm with most of the material -100 +50 mm.

* The trade name of a high-intensity magnetic separator.


MINED ORE
1.1
FEEDER GRIZZLY
35 H.P.
1.2
JAW CRUSHER
200 H.P.
-170mm
-110mm
1.3
STANDARD
CONE CRUSHER
100 H.P.
-75mm
1
CLASSIFIED
PILES
DUST COLLECTORS (3)
15 H.P.
1.4
ALLIS-CHALMERS SCREEN
20 H.P.
1.7
SHORTHEAD
CONE CRUSHER
125 H.P.
-10mm
2
1.6
DRAFT FAN
100 H.P.
1.5
ROTARY
DRYER
100 H.P.
400T
"A"
600T
"A"
150T
"B"
-50mm
+20mm
CRUDE PRODUCT PILE
• - SAMPLING POINTS
② - SAMPLE No.
---- - DUST FLOW

NOTE: 3 Dust Collectors (not shown) 16 H.P. each.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
1.1	Feeder Grizzley	-
1.2	Jaw Crusher	56
1.3	4' Standard Cone	28
1.4	Allis-Chalmers Screen	-
1.5	Rotary Dryer	54
1.6	Draft Fan	75
1.7	4-1/4' Shorthead Cone	24
1.8	Jaw Crusher Dust Collector	10
1.9	Cone Crusher Dust Collector	10
1.10	Screen Dust Collector	9

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 22/08/83

CHECKED DCS
DATE 20/08/84

ORE PREPARATION CIRCUIT
FLOW DIAGRAM

PLANT of INCORE
BIC - HAVELOCK, ONTARIO

PROJECT No. 20010

Size distributions for secondary and tertiary crusher products are as follows.

	Product (% Passing)	
Size (mm)	Secondary Crusher	Tertiary Crusher
100	100	-
75	95.7	-
50	87.5	-
31.5	-	100
25	56.8	98.7
19	48.6	94.2
12.5	38.0	81.3
4.75	24.5	50.6
1.18	16.6	33.5
0.3	7.1	20.9

Grindability. The Bond and Hardgrove Indices on the ore were determined to be 13.8 kWh/T and 41, respectively.

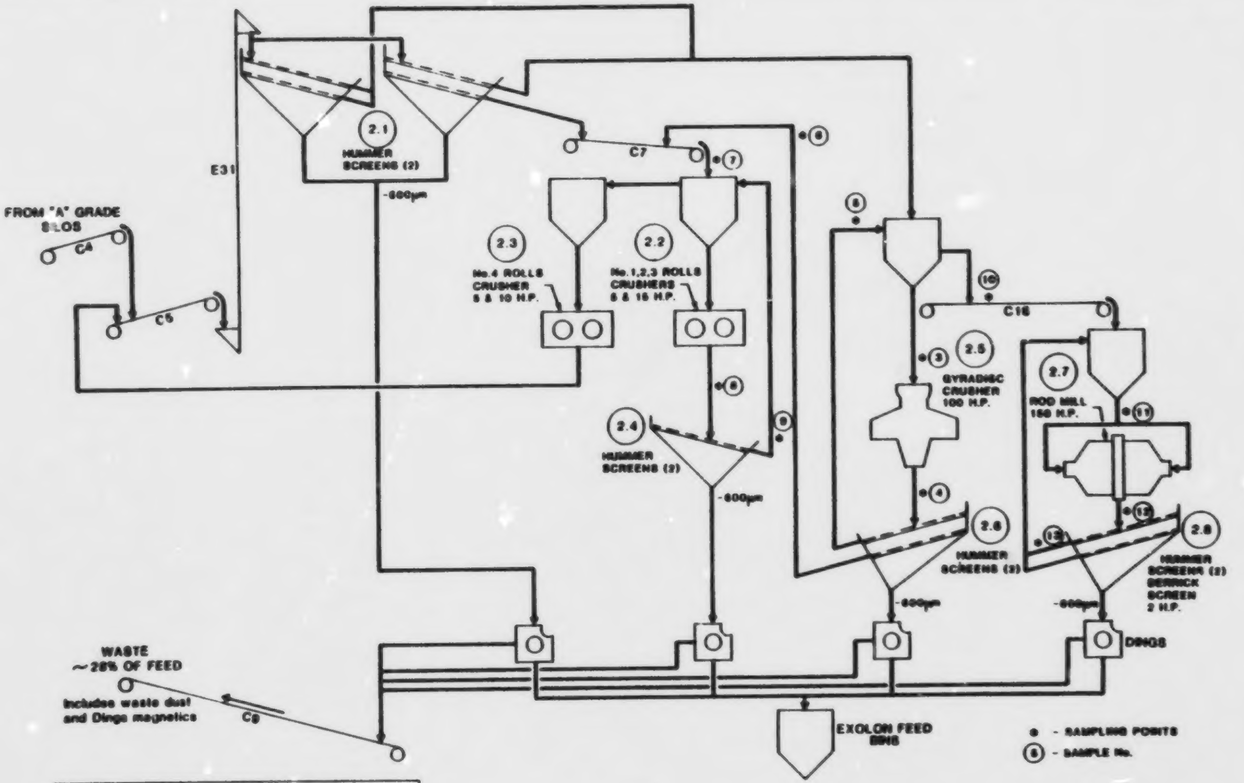
The Exolon Feed Preparation Circuit

The circuit is shown schematically on page 108. Rated power and average demand are summarized on the sketch.

The **flowrate** of beneficiated material from this circuit is 30 t/h.

Particle size distribution of discharge material from each of the comminution machines is characterized as follows.

	Discharge (% Passing)		
Size (mm)	Gyradisc	Rolls	Rod Mill
25	100	-	-
12.5	91	-	-
9.5	78	100	100
2.36	42	87	99
1.18	32	62	91
0.6	18	26	38
0.3	8	10	19
0.15	2	4	10


FROM "A" GRADE SILOS
C4
C5
E31
2.1
HUMMER SCREENS (2)
-600μm
C7
7
9
2.3
No.4 ROLLS CRUSHER 5 & 10 H.P.
2.2
No.1,2,3 ROLLS CRUSHERS 5 & 15 H.P.
8
2.4
HUMMER SCREENS (2)
-600μm
5
10
C16
3
2.5
GYRADISC CRUSHER 100 H.P.
4
2.6
HUMMER SCREENS (2)
-600μm
2.7
ROD MILL 150 H.P.
11
12
13
2.8
HUMMER SCREENS (2) DERRICK SCREEN 2 H.P.
-600μm
DINGS
WASTE ~28% OF FEED
Includes waste dust and Dings magnetics
C9
EXOLON FEED BINS
• - SAMPLING POINTS
(5) - SAMPLE No.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
2.1	4'x10' Hummer Screens (2)	1.6
2.2	#1, 2, 3 Rolls Crushers	8.3 29
2.3	#4 Rolls Crusher	1.7 5
2.4	4'x10' Hummer Screens (2)	1.6
2.5	36" Gyradisc Crusher	44
2.6	4'x10' Hummer Screens (2)	1.6
2.7	6'x12' Rod Mill	74
2.8	4'x10' Hummer Screens (2) 3'x10' Derrick Screen	1.6 0.8

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 22/09/83
CHECKED DCS
DATE 20/09/84

EXOLON FEED PREPARATION FLOW DIAGRAM

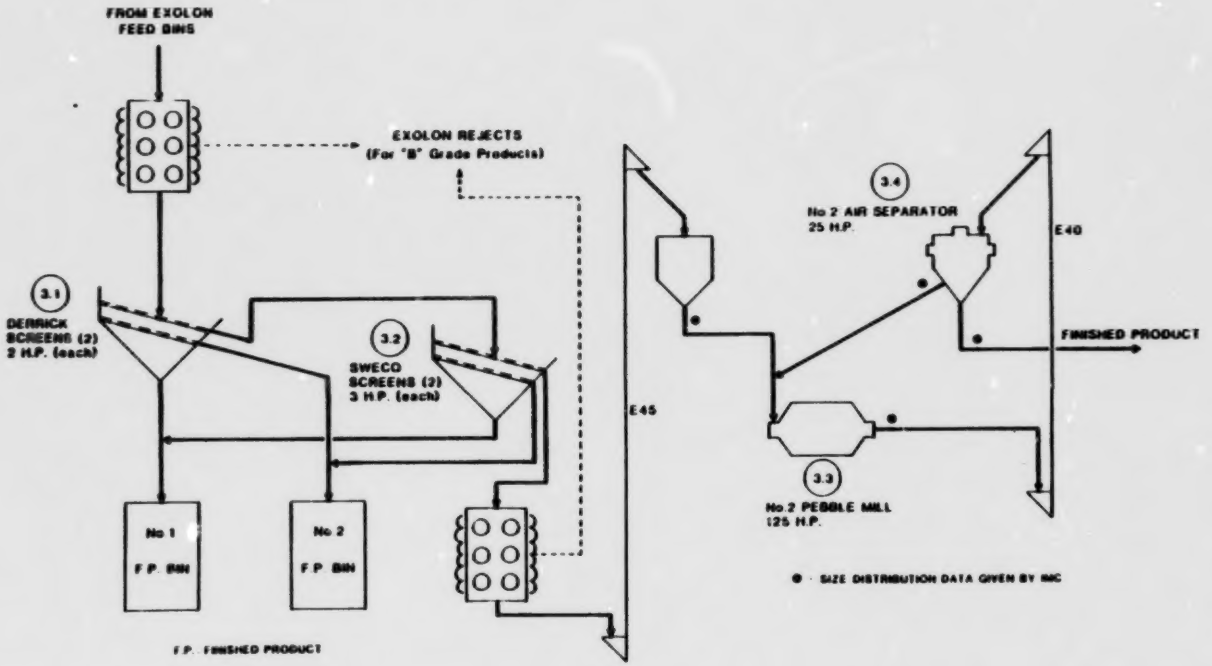
PLANT No. IMCORE
IMC - HAVELOCK, ONTARIO
PROJECT No. 20010

Fine Grinding

Fine grinding involves No. 2 and 3 pebble mills. No. 2 pebble mill circuit is shown schematically on page 110. Rated power and average demand of the equipment are summarized on the sketch.

The **particle size distribution** of the feed and product of the mill circuit are summarized as follows.

	% Passing	
Size (µm)	Feed	Product
850	100	-
600	96	-
500	66	-
425	36	-
300	4	-
250	2	-
106	-	-
75	-	100
45	-	99
30	-	89
20	-	67
10	-	38
6	-	25
2	-	12


FROM EXOLON FEED BINS
EXOLON REJECTS (For "B" Grade Products)
3.1
DERRICK SCREENS (2) 2 H.P. (each)
3.2
SWECO SCREENS (2) 3 H.P. (each)
No 1 F.P. BIN
No 2 F.P. BIN
E45
3.4
No 2 AIR SEPARATOR 25 H.P.
E40
FINISHED PRODUCT
3.3
No.2 PEBBLE MILL 125 H.P.

F.P. FINISHED PRODUCT

● - SIZE DISTRIBUTION DATA GIVEN BY IMC

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
3.1	3'x10' Derrick Screens(2)	1.6
3.2	Sweco Screens (2)	-
3.3	#2 Pebble Mill	75
3.4	#2 Separator	8

CANADA CEMENT LAFARGE LTD.
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No.2 PEBBLE MILL CIRCUIT
FLOW DIAGRAM

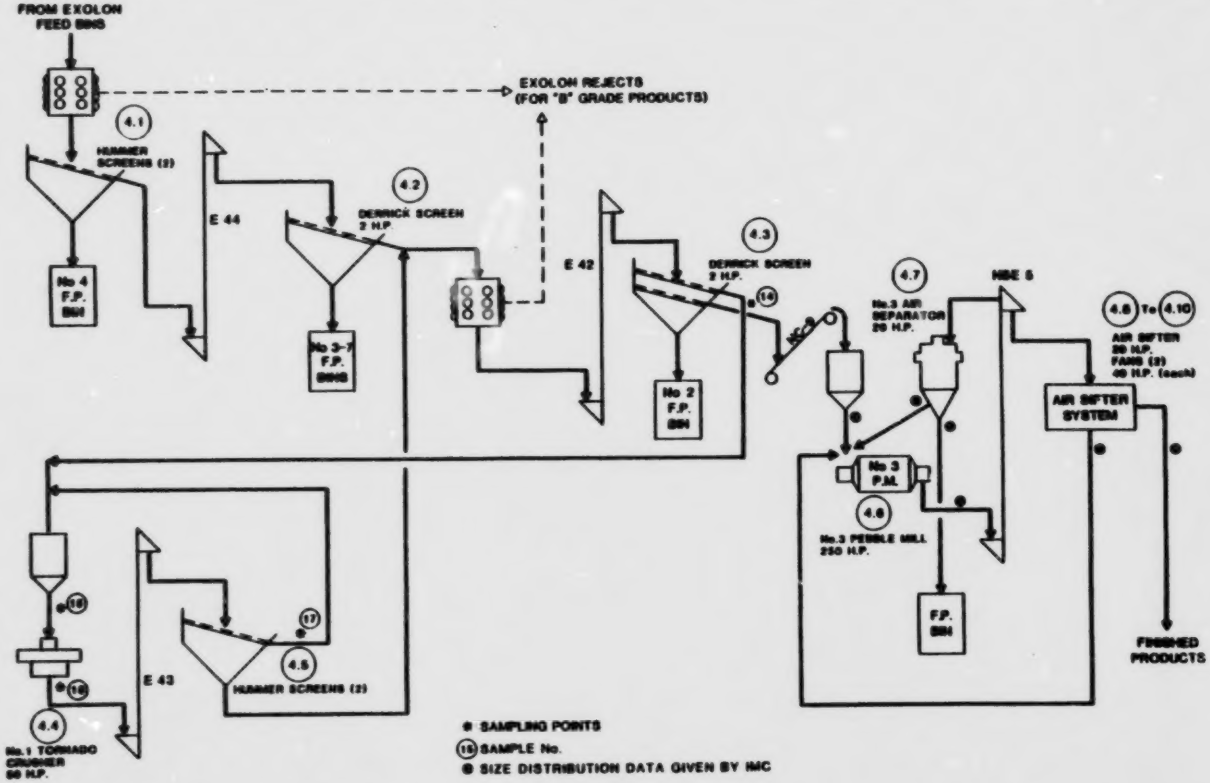
PLANT N° IMCORE
IMC - HAVELOCK, ONTARIO
PROJECT No. 20010

No. 3 pebble mill circuit is shown schematically on page 112. Rated power and average demand are summarized on the sketch.

Circuit feed and separator fines are characterized as follows.

	% Passing	
Size (μm)	Feed	Product
850	100	-
600	97	-
500	73	-
425	47	-
300	14	-
250	9	-
106	-	-
75	-	100
45	-	98
30	-	93
20	-	81
10	-	55
6	-	39
2	-	19

The **flowrates** for the pebble mill circuits were supplied by IMC.


FROM EXOLON FEED BINS
EXOLON REJECTS (FOR "B" GRADE PRODUCTS)
4.1
HUMMER SCREENS (2)
No 4 F.P. BIN
E 44
4.2
DERRICK SCREEN 2 H.P.
No 3-7 F.P. BINS
E 42
4.3
DERRICK SCREEN 2 H.P.
14
No 2 F.P. BIN
4.7
No.3 AIR SEPARATOR 20 H.P.
HBE 5
4.8 To 4.10
AIR SIFTER 20 H.P. FANS (2) 40 H.P. (each)
AIR SIFTER SYSTEM
No 3 P.M.
4.6
No.3 PEBBLE MILL 250 H.P.
F.P. BIN
FINISHED PRODUCTS
18
16
4.4
No.1 TORNADO CRUSHER 50 H.P.
E 43
17
4.5
HUMMER SCREENS (2)
● SAMPLING POINTS
15 SAMPLE No.
● SIZE DISTRIBUTION DATA GIVEN BY IMC

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	KW AVG.
4.1	4'x15' Hummer Screens(4)	3.2
4.2	4'x10' Derrrick Screen	0.8
4.3	3'x10' Derrick Screen	0.8
4.4	#1 Tornado Crusher	28
4.5	4'x10' Hummer Screens(2)	1.6
4.6	#3 Pebble Mill	183
4.7	#3 Air Separator	7
4.8	Air Sifter - Apex 700	6
4.9	Fan #1	12
4.10	Fan #2	15

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DATE 20/09/84

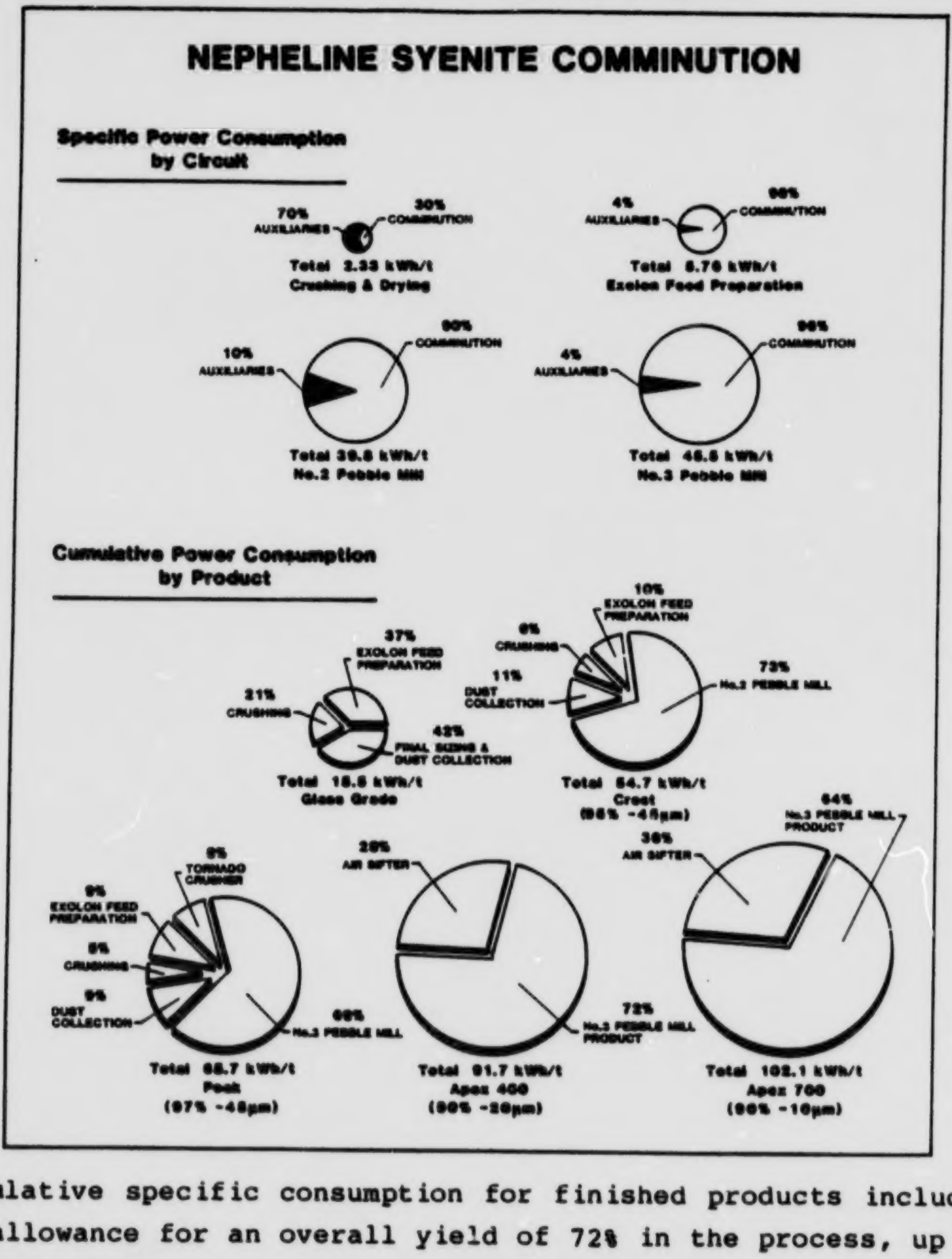
No 3 PEBBLE MILL CIRCUIT
FLOW DIAGRAM

PLANT of IMCORE DIVISION
IMC - HAVELOCK, ONTARIO

PROJECT No: 20010

Results

The specific energy consumption in the crushing and grinding circuits is summarized in the following diagram.



Cumulative specific consumption for finished products includes an allowance for an overall yield of 72% in the process, up to and including, the Dings magnetic separators. Material is rejected from the process by dust wasting. Material rejected by the Exolon magnetic separators is not wasted but downgraded to "B" products.

Other than in the crushing and drying circuit, plant dust collectors are not generally dedicated to any one machine or circuit. Thus, an overall consumption of 5.9 kWh/t was determined, based on electrical measurements on the dust collectors in question and the total plant production rate. This figure is included in all cumulative specific energies.

Final sizing of glass grade products includes screening and 25% of the tornado crusher demand. Pebble mill products show the majority of their consumption from the fine grinding stage of the process. Cumulative consumption for No. 3 pebble mill product includes 75% of tornado crusher demand.

Conclusions

Consumption by auxiliaries is significant in the crushing and drying circuit. Auxiliary consumption arises mainly from the dryer drive and I.D. fan. Comminution comprises the major portion of specific consumption in the other circuits. Specific consumption is higher in circuits involving high fineness.

Cumulative consumption for the filler (Apex) products shows that the air sifter classification stage adds a considerable amount of consumption to the product. The air sifter involves classification only.

At the time of the study, the plant was operating under typical conditions. These results are considered to provide a representative "snapshot" of comminution consumption in the nepheline syenite industry.

Recommendations

Test the efficiency of autogenous milling to reduce the number of comminution stages.

REF 434-092
PROCÉDÉ Plasdex® PROCESS
MONTRÉAL, QUÉBEC

POTASH

POTASH

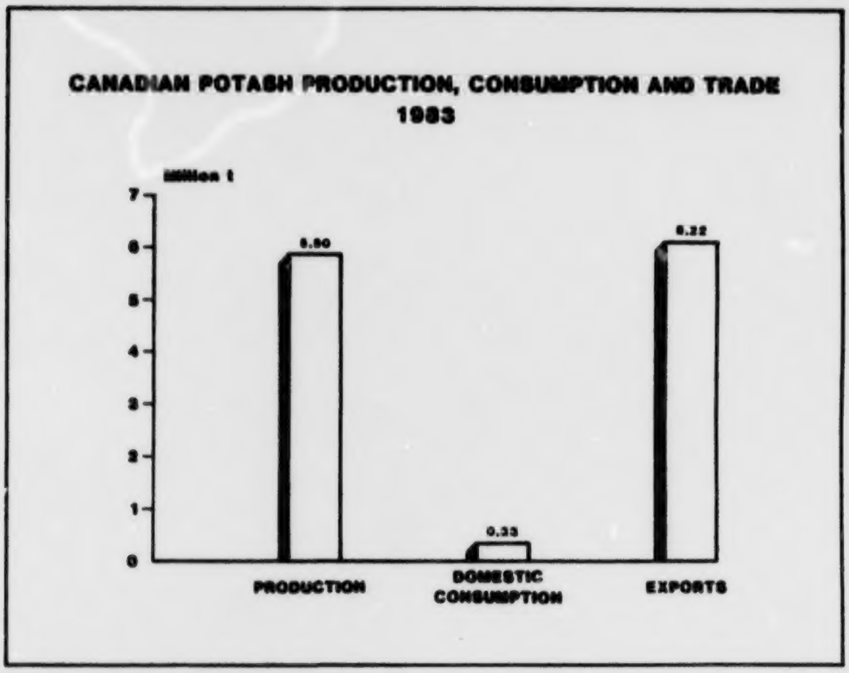
Participating Company

P.C.S. MINING LTD.
Cory Division

Plant Location

Saskatoon, Saskatchewan

Potash: Comminution plays minor role



Source: Canadian Mining Journal, February 1984.

Comminution power requirement : 6.1 kWh/t.

Estimated comminution power requirement by the potash industry in 1982 : 40,200,000 kWh.

Background

Potash was discovered in Canada in the 1940's and limited production took place in the 1950's. The high growth years occurred in the next decade with Canada becoming the world's second largest producer, after the U.S.S.R., by 1968.

The potash industry is located mainly in Saskatchewan. However, potash production has recently begun in New Brunswick.

Canada exports 95% of its production. The United States accounts for 70% of total exports.

Products and Uses

Potash is a source of potassium which is one of the major elements required for plant growth. Thus, 90% of potash is in fertilizers.

It is marketed in Canada in the form of potassium chloride (KCl) called muriate of potash with a chemical composition of:

Typical Chemical Composition of Muriate of Potash	
	%
K	50.5
Mg	0.17
Ca	0.02
Na	1.05
Cl	47.86
SO_4	0.04
Insoluble	0.30

Potash is also sold in a refined form for industrial uses.

The marketed products are classified according to size as follows:

Representative Particle Size Ranges of Potash Products	
Product	Size Range (mm)
Granular	0.8 - 3.4
Coarse	0.6 - 2.4
Standard	0.2 - 1.7
Soluble	0.15 - 0.4
Suspension	0.075 - 0.4
Refined KCl	fine

The Production Process

Potash ore occurs as a mixture of halite (sodium chloride) and sylvite (potassium chloride). The two compounds are present as distinct crystals with some clay adhering to the crystal surfaces.

In the production process, ore is reduced by crushing and grinding to a sufficiently small size to separate the individual crystals. The ore is then scrubbed to remove the clay. Sylvite and halite are separated in a flotation process and the halite sent to tailings. The sylvite is centrifuged and dried before classification into the various products. The coarsest product is produced by a special operation called compaction, wherein crystals of sylvite are "pressed" together to form a coarser material. Final classification is done by screening. These are referred to as "pink" products, due to the color imparted by some remaining impurities.

More highly refined potash products are made in a special crystallizing operation. The process is temperature dependent and requires tight control to recover a basically pure KCl product. Refined material from crystallization is referred to as "white" product.

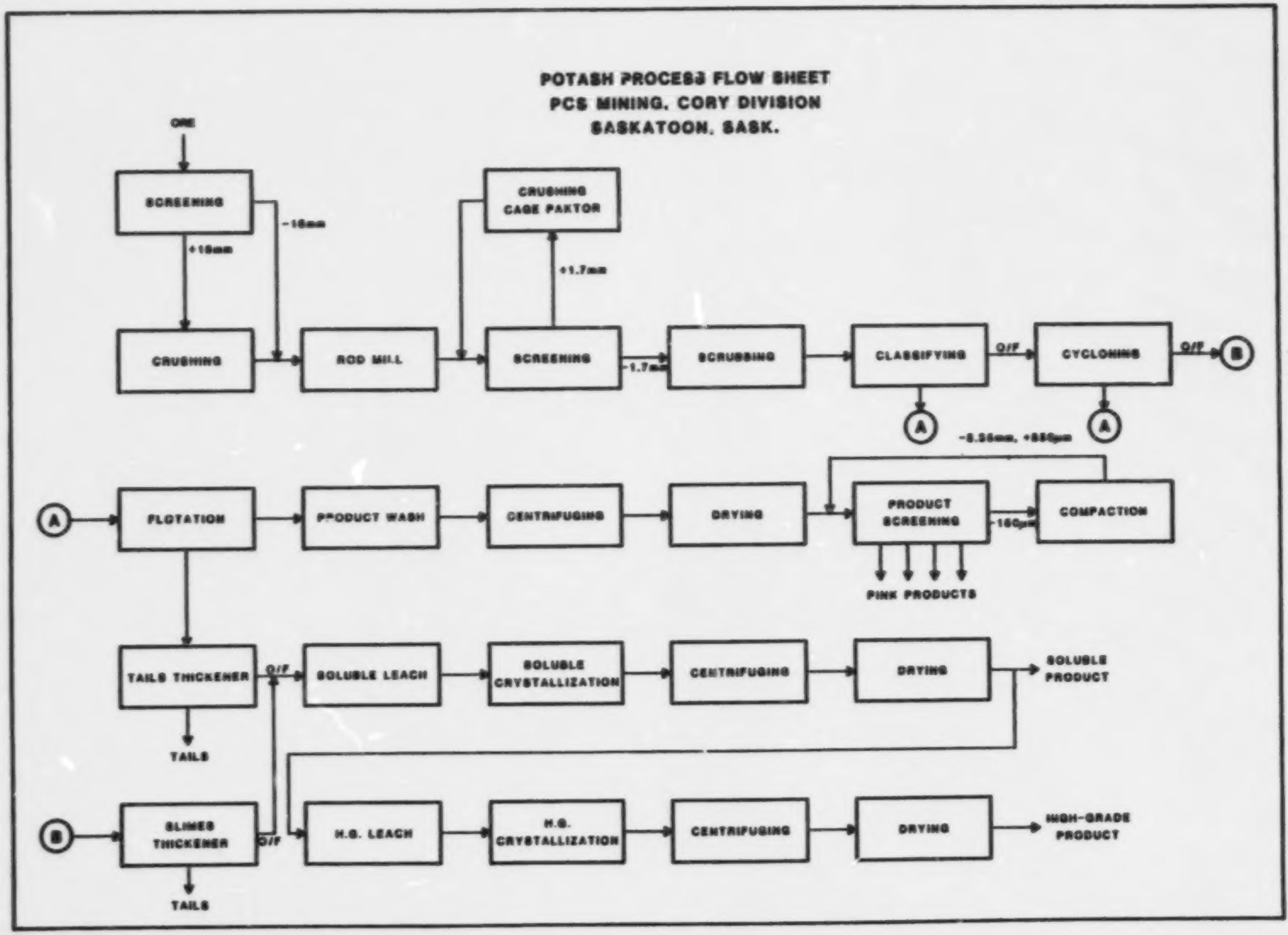
A typical process flow sheet is shown overleaf.

The Role of Comminution

There are two stages involving comminution in the potash process.

Crushing, where mined ore is reduced to a size suitable for scrubbing and flotation.

Post-compaction Crushing, where compacted flake is crushed to product specification.



POTASH PROCESS FLOW SHEET
PCS MINING, CORY DIVISION
SASKATOON, SASK.

ORE
SCREENING
-16mm
+16mm
CRUSHING
ROD MILL
CRUSHING CAGE PAKTOR
+1.7mm
SCREENING
-1.7mm
SCRUBBING
CLASSIFYING
O/F
CYCLONING
O/F
B
A
A
-3.35mm, +850μm
A
FLOTATION
PRODUCT WASH
CENTRIFUGING
DRYING
PRODUCT SCREENING
-150μm
COMPACTION
PINK PRODUCTS
TAILS THICKENER
O/F
SOLUBLE LEACH
SOLUBLE CRYSTALLIZATION
CENTRIFUGING
DRYING
SOLUBLE PRODUCT
TAILS
B
SLIMES THICKENER
O/F
H.G. LEACH
H.G. CRYSTALLIZATION
CENTRIFUGING
DRYING
HIGH-GRADE PRODUCT
TAILS

Comminution at Cory Division

The Crushing Circuit

The crushing circuit is shown schematically on page 120. Rated power (HP) and average demand (kW) in operation are summarized on the sketch.

The average **production rate** of the crushing circuit is 450 t/h, based on plant records.

Grindability testing resulted in a Bond Index of 13.55 kWh/T and a Hardgrove Index of 55.

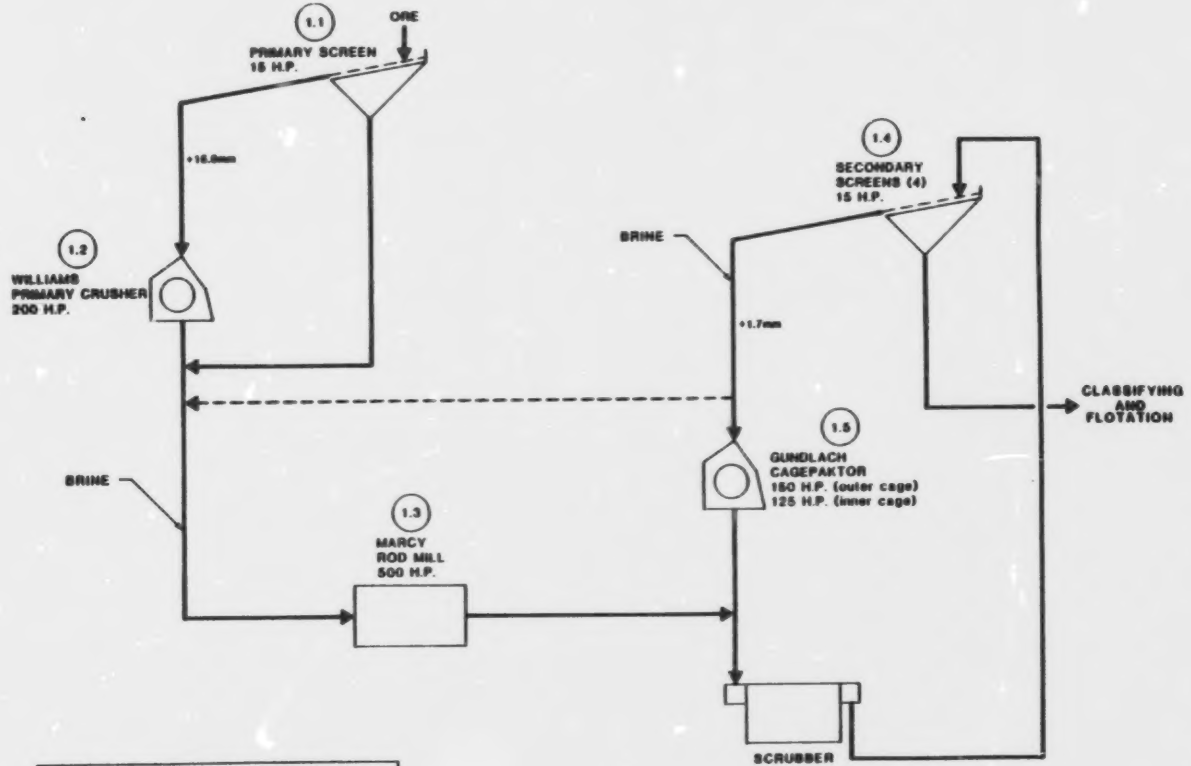
Particle size distribution of ore fed to the circuit and Cagepaktor discharge are characterized in the following table.

	% Passing	
Size	Ore	Cagepaktor Discharge
32.0 mm	100	
18.9	88.0	
9.42	77.2	100
4.75	64.0	98.5
2.36	48.9	78.6
1.40	34.1	39.9
850 µm	28.7	30.1
500	18.1	15.2
250	10.3	8.2
106	4.8	4.5

Post-compaction Crushing

The product screening and compaction circuit is shown schematically on page 121. Rated power and average demand are summarized on the sketch.

The estimated **flowrate** for the circuit is 150 t/h.


1.1
PRIMARY SCREEN
15 H.P.
ORE
+16.0mm
1.2
WILLIAMS
PRIMARY CRUSHER
200 H.P.
BRINE
1.3
MARCY
ROD MILL
500 H.P.
1.4
SECONDARY
SCREENS (4)
15 H.P.
BRINE
+1.7mm
1.5
GUNDLACH
CAGEPAKTOR
150 H.P. (outer cage)
125 H.P. (inner cage)
SCRUBBER
CLASSIFYING
AND
FLOTATION

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	KW AVG.
1.1	PRIMARY SCREEN	4.7
1.2	WILLIAMS PRIMARY CRUSHER	127
1.3	MARCY ROD MILL	370
1.4	SECONDARY SCREENS (4)	3.7
1.5	CAGEPAKTOR	
	OUTER CAGE	73
	INNER CAGE	47

CANADA CEMENT LAFARGE LTD.
MONTREAL

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DATE 3/04/84
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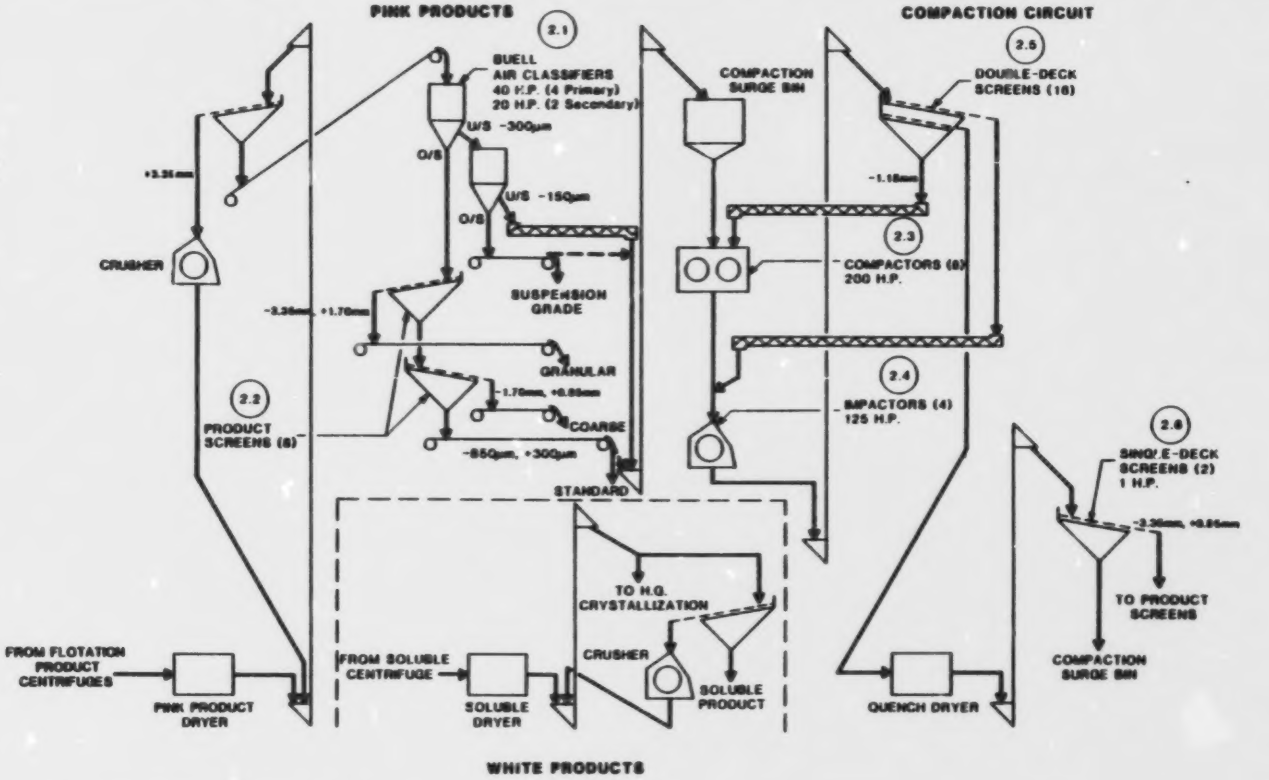
DATE 20/09/84

ORE CRUSHING FLOW DIAGRAM

PLANT of CORY DIVISION
PCS MINING - SASKATOON

PROJECT No. 20010


PINK PRODUCTS
2.1
BUELL
AIR CLASSIFIERS
40 H.P. (4 Primary)
20 H.P. (2 Secondary)
U/S -300μm
O/S
U/S -150μm
O/S
+3.35mm
CRUSHER
SUSPENSION
GRADE
-3.35mm, +1.70mm
GRANULAR
2.2
PRODUCT
SCREENS (8)
-1.70mm, +0.85mm
COARSE
-850μm, +300μm
STANDARD
FROM FLOTATION
PRODUCT
CENTRIFUGES
PINK PRODUCT
DRYER
COMPACTION
SURGE BIN
COMPACTION CIRCUIT
2.5
DOUBLE-DECK
SCREENS (16)
-1.18mm
2.3
COMPACTORS (8)
200 H.P.
2.4
IMPACTORS (4)
125 H.P.
2.6
SINGLE-DECK
SCREENS (2)
1 H.P.
-3.35mm, +0.85mm
TO PRODUCT
SCREENS
COMPACTION
SURGE BIN
QUENCH DRYER
TO H.G.
CRYSTALLIZATION
CRUSHER
SOLUBLE
PRODUCT
FROM SOLUBLE
CENTRIFUGE
SOLUBLE
DRYER
WHITE PRODUCTS

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
2.1	BUELL AIR CLASSIFIERS	
	PRIMARY (4)	15.3
	SECONDARY (2)	6.2
2.2	PRODUCT SCREENS (8)	3.5
2.3	COMPACTORS (8)	140
2.4	IMPACTOR CRUSHERS (4)	33
2.5	COMPACTION DOUBLE-DECK SCREENS (16)	3.5
2.6	COMPACTION SINGLE-DECK SCREENS (2)	0.5

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 07/10/83
CHECKED DCS
DATE 20/09/84

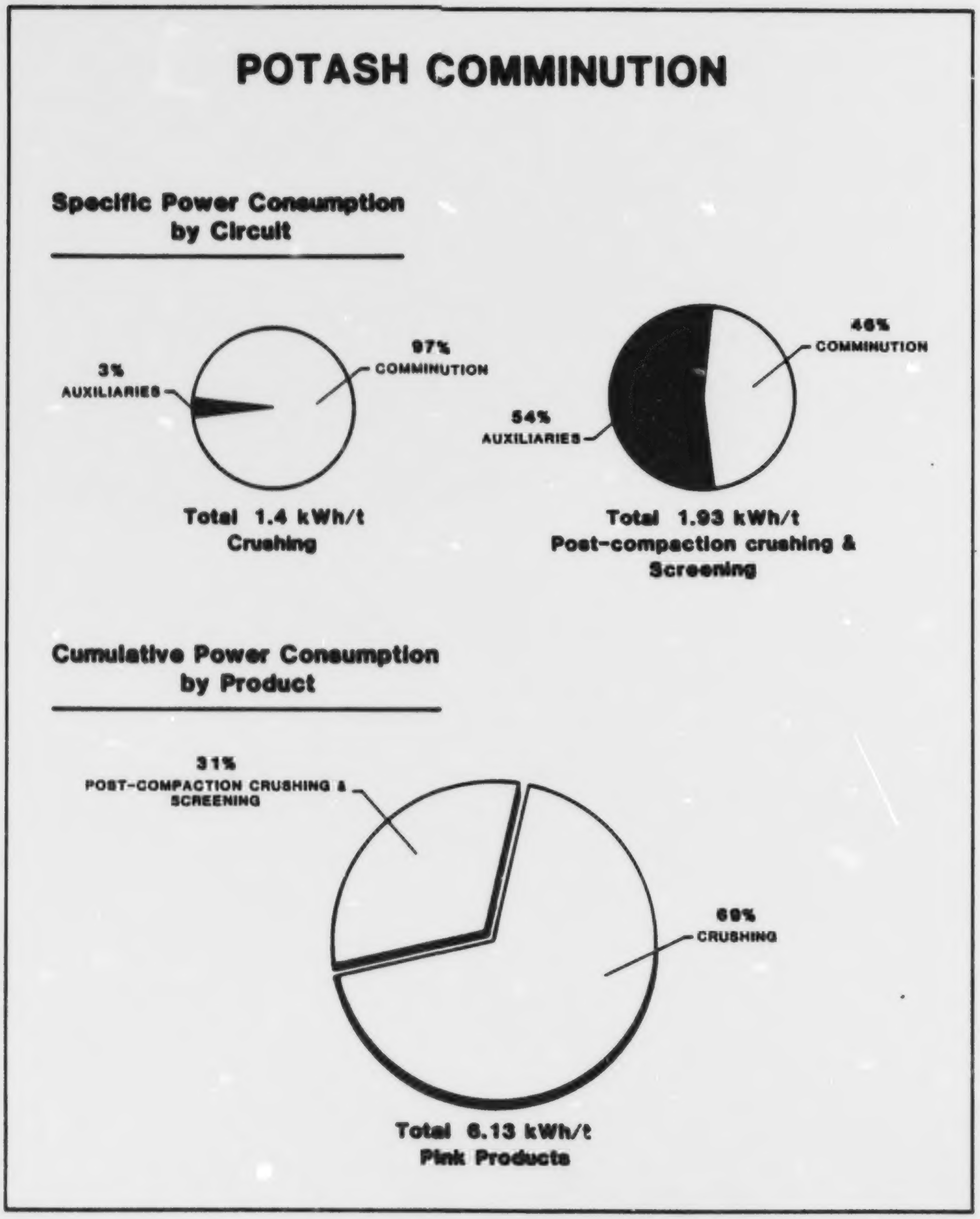
PRODUCT SCREENING & COMPACTION
FLOW DIAGRAM

PLANT CORY DIVISION
PCS MINING-SASKATOON

PROJECT No. 20010

Results

Specific energy consumption for comminution and associated operations in potash processing is summarized in the following diagram.



Specific consumption is reported only for pink products. Processing of white products is mainly by solution involving no comminution.

Consumption for compaction was calculated to be 7.5 kWh/t of finished product. This is not included in the cumulative power consumption since compaction is, in a sense, the opposite of comminution.

Conclusions

The consumption for comminution and auxiliaries is low. Practically all consumption in the initial crushing circuit is for comminution, while for post-compaction crushing and product screening, comminution accounts for a much smaller proportion. This is a result of the large number of screens and the air classifiers.

Crushing circuit consumption accounts for a major portion of product cumulative specific energy. This is due to the fact that the yield in the flotation circuit is 33%, requiring 3 tonnes of ore to be crushed for each tonne of product.

Considering the light loading of the four crushers in the compaction circuit, it may be more efficient to use two of the crushers at a time for processing. This would also facilitate maintenance by freeing two crushers as back-ups.

In summary, comminution is not a major energy consumer in the potash process.

Recommendations

None.

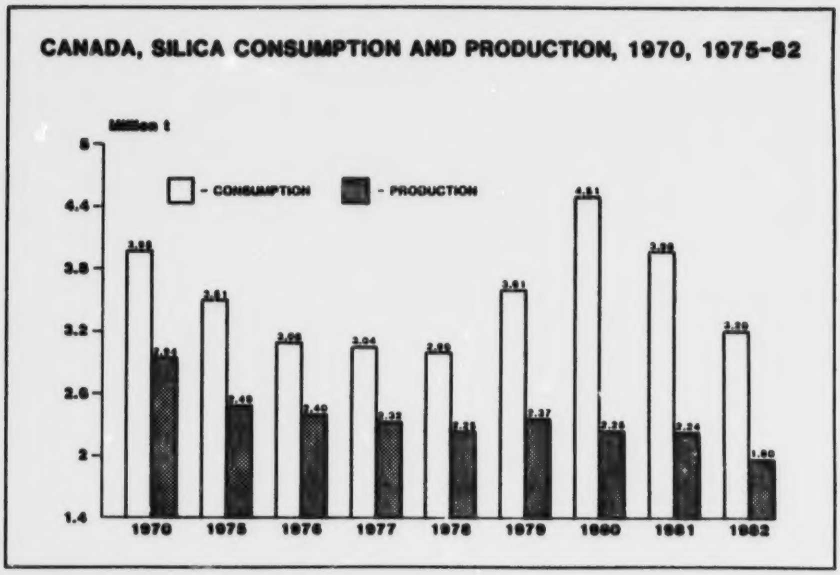
PROCEDE Plandex R PROCESS
MONTREAL QUEBEC

SILICA

SILICA

Plant closures and competitive market pressures resulting from the recession made it impossible to visit a producing silica operation. The Phase I data base information was assembled from published literature and discussions with operators and consultants.

Silica: Variable specific power consumption - high tonnages


CANADA, SILICA CONSUMPTION AND PRODUCTION, 1970, 1975-82

Source: Canadian Minerals Yearbook 1982, EMR Canada.

Comminution power requirements :

ferro silicon grades	**-**	**1.3 kWh/t.**
glass sand grades	**-**	**22.9 kWh/t.**
ceramic & fiberglass grades	**-**	**115-175 kWh/t.**

Estimated comminution power requirement by the Canadian silica industry : 35,000,000 kWh/yr.*

Background

Production from the Canadian silica industry has decreased since 1979 due to reduced demand from the major consumers, i.e., the steel and base metal industries, housing, automobile and container industries. Ontario and Quebec account for 65-70% of total production, and most of this by a single company. In addition to eleven quartz-silica sand producers, numerous companies in the ferrous, base metal and cement sectors also process silica for their in-house needs.

* Assumes distribution of 75% lump and flux, 15% glass and 10% fine ground.

Products and Uses

Silica is consumed in a variety of industries as shown in the table below.

CANADA - ESTIMATED CONSUMPTION OF SILICA, BY INDUSTRIES		
	1981 (tonnes)	%
Foundry sand	1,085,481	27
Glass manufacture (including glass fibre)	951,442	24
Smelter flux[1]	837,203	21
Refractory brick mixes, cements	359,163	9
Artificial abrasives	125,706	3
Metallurgical	143,447	4
Chemicals	39,430	1
Gypsum products	2,314	-
Concrete products	211,608	5
Fertilizer, stock poultry feed	3,982	-
Other[2]	223,975	6
TOTAL	3,983,751	100

Source: Statistics Canada; Energy, Mines and Resources, Canada.

[1] Producers' shipments of quartz and silica for flux purposes.

[2] Includes asbestos products, ceramic products, frits and enamels, paper and paper products, roofing and other minor uses.

Approximately one million tonnes per annum of silica sand enters Canada for use in the glass and foundry industries. These sands compete with Canadian grades due to their lower operating and transportation costs. Furthermore, these U.S.A. sands have a narrow size range of rounded grains; qualities heretofore unattainable from quartzite deposits in Canada, yet required for foundry sand applications.

Price per tonne of silica at the processing mine and mill vary from $1 for flux grade, to $5-10 for ferrosilicon grades, to $30-35 for glass grades, to $40-50 for ceramic and filter grades. Transportation costs of the finished product to the customer can be in the same magnitude as the selling price and is therefore a key component in the marketing of a mines product.

The chemical and particle size specifications of a silica product vary considerably and are set by the market. A typical quartzite deposit and its products would have the following chemical composition;

CHEMICAL COMPOSITION	%
SiO_2	98.7
Al_2O_3	0.6
Fe_2O_3	0.04
CaO	0.005
MgO	0.015
K_2O	0.015
Na_2O	0.013
TiO_2	0.02
LOI	0.15

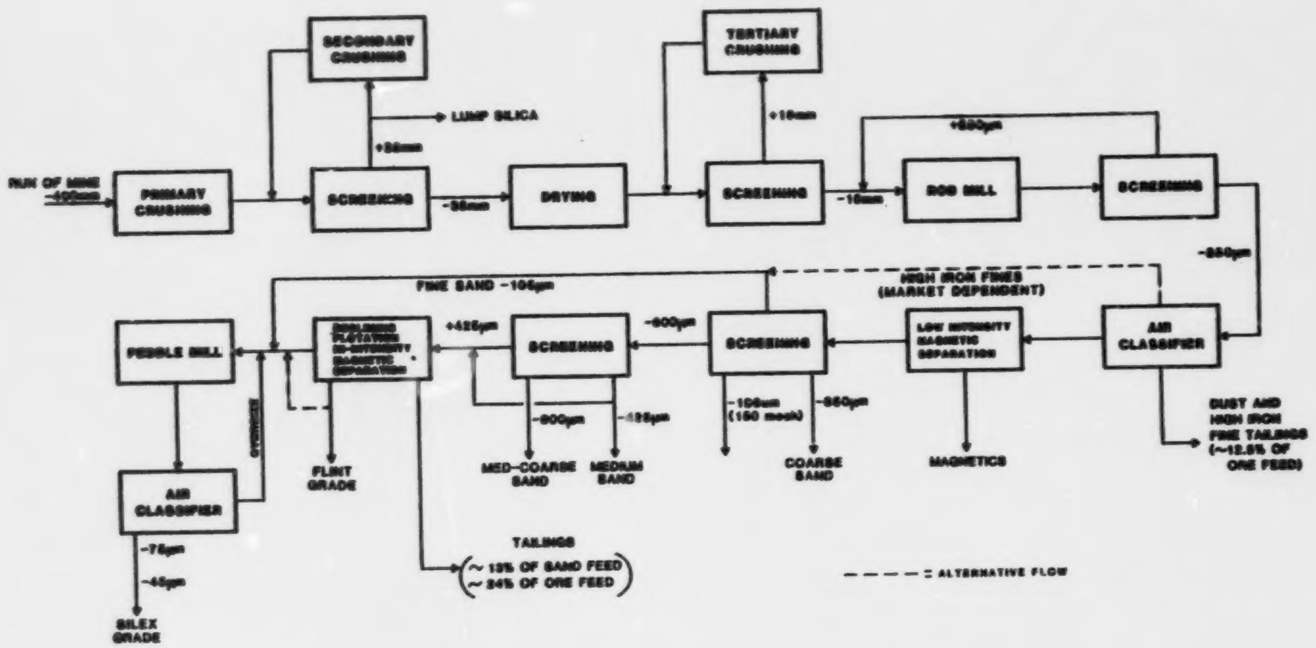
The size specifications for the principal products are -90 +40 mm for lump silica, -700 +74 μm for glass sand, -74 μm for asbestos cement silica and -45 μm for cleanser and ceramic grade silica.

The Production Process

A typical process flow sheet is shown overleaf.

The process is highly dependent upon the market being served and by the characteristics of the quartz-silica sand orebody. We have attempted to describe a typical process treating a quartzite deposit for the ferrosilicon, glass, fiberglass, ceramic and filler markets. The process involves crushing-screening and drying to produce lump silica for ferrosilicon use; followed by coarse rod mill grinding - screening - air classification and magnetic separation for regular glass grade products; followed by flotation - drying and high intensity magnetic separation for premium glass grade products; followed by pebble mill grinding and classification for ceramic, filler and fiberglass grade products.

TYPICAL SILICA PROCESS FLOW SHEET


RUN OF MINE
-400mm
PRIMARY CRUSHING
SCREENING
SECONDARY CRUSHING
+38mm
LUMP SILICA
-38mm
DRYING
SCREENING
TERTIARY CRUSHING
+10mm
-10mm
ROD MILL
SCREENING
+850µm
-850µm
AIR CLASSIFIER
DUST AND HIGH IRON FINE TAILINGS (~12.5% OF ORE FEED)
HIGH IRON FINES (MARKET DEPENDENT)
LOW INTENSITY MAGNETIC SEPARATION
MAGNETICS
SCREENING
-106µm (150 mesh)
-850µm
COARSE SAND
-600µm
SCREENING
-600µm
MED-COARSE SAND
-425µm
MEDIUM SAND
+425µm
FINE SAND -106µm
FLOTATION
HI-INTENSITY
MAGNETIC
SEPARATION
FLINT GRADE
TAILINGS
(~ 13% OF SAND FEED
~ 24% OF ORE FEED)
PEBBLE MILL
OVERSIZE
AIR CLASSIFIER
-75µm
-45µm
SILEX GRADE
- - - - = ALTERNATIVE FLOW

The Role of Comminution

There are three comminution steps in silica processing.

Crushing, where ore is reduced and dried to make a lump silica product and feed for primary grinding.

Primary grinding and classification, where crushed material is ground, classified to remove abraded iron and screened into various glass grades and feed to flotation and fine grinding.

Fine grinding, where sand is ground and classified to make various products.

Comminution in a Typical Silica Operation

The Crushing Circuit

The typical circuit is shown schematically on page 129.

A lump silica product (-90 +40 mm) for the ferrosilicon market could be removed prior to the drying stage.

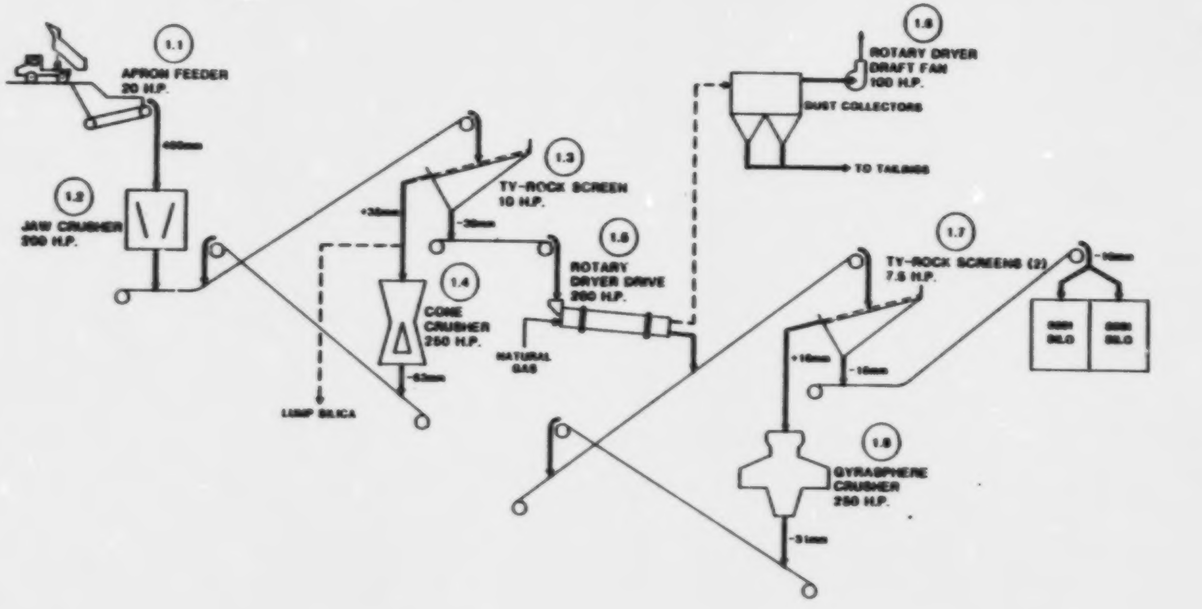
The circuit has 3 stages of crushing with intermediate screening and a drying stage, to produce -16 mm feed to the primary grinding circuit.

The production rate of the circuit is taken as 135 t/h.

Primary Grinding and Classification

This typical circuit is illustrated on page 130.

The dry grinding circuit consists of a rod mill operating in closed circuit with screens, the undersize of which is air classified to remove a fine fraction that is also high in iron


1.1
APRON FEEDER
20 H.P.
400mm
1.2
JAW CRUSHER
200 H.P.
1.3
TY-ROCK SCREEN
10 H.P.
+30mm
-30mm
1.4
CONE
CRUSHER
250 H.P.
-62mm
LUMP SILICA
1.5
ROTARY
DRYER DRIVE
200 H.P.
NATURAL
GAS
1.6
ROTARY DRYER
DRAFT FAN
100 H.P.
DUST COLLECTORS
TO TAILINGS
1.7
TY-ROCK SCREENS (2)
7.5 H.P.
+10mm
-10mm
1.8
GYRASPHERE
CRUSHER
250 H.P.
-31mm
SILO
SILO

NOTE: 2 Dust Collectors (not shown) 2 X 50 H.P.

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
1-1	Apron Feeder	8
1-2	Jaw Crusher	50
1-3	Ty-Rock Screen - 5'x12'	4
1-4	5-1/2' Cone Crusher	100
1-5	Rotary Dryer Drive	75
1-6	Rotary Dryer Draft Fan	58
1-7	Ty-Rock Screen - 4'x12' (2)	3
1-8	Gyrasphere Crusher	150
1-9	Crushing Plant Dust Collector	29
1-10	Screening Plant Dust Collector	33

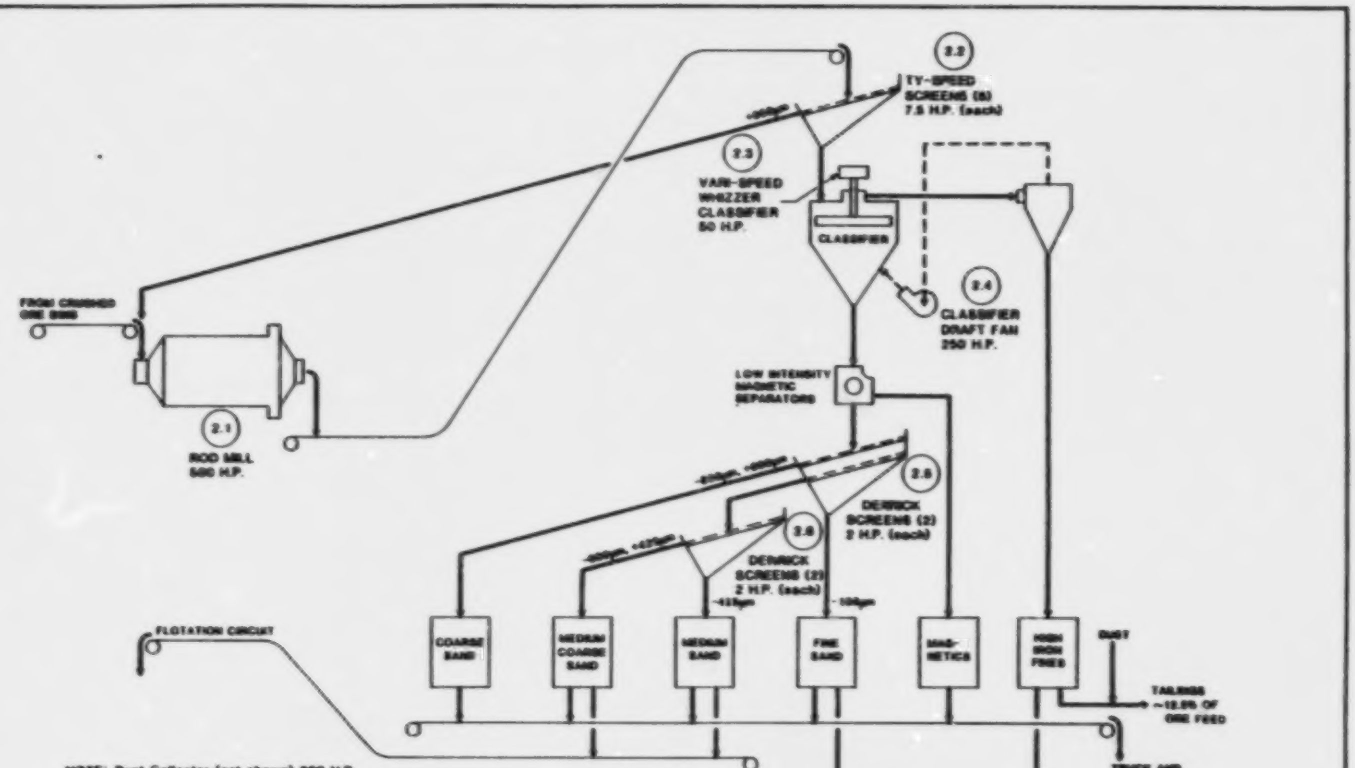
CANADA CEMENT LAFARGE LTD.
MONTREAL

Drawn GFJ
Date 18-09-84
Checked DCS
Date 20/09/84

CRUSHING AND DRYING
TYPICAL FLOW DIAGRAM

Plant nº ____________

PROJECT No. **20010**


FROM CRUSHED ORE BINS
2.1
ROD MILL 500 H.P.
2.2
TY-SPEED SCREENS (8) 7.5 H.P. (each)
2.3
VARI-SPEED WHIZZER CLASSIFIER 50 H.P.
CLASSIFIER
2.4
CLASSIFIER DRAFT FAN 250 H.P.
LOW INTENSITY MAGNETIC SEPARATORS
2.5
DERRICK SCREENS (2) 2 H.P. (each)
2.6
DERRICK SCREENS (2) 2 H.P. (each)
-425µm
-106µm
COARSE SAND
MEDIUM COARSE SAND
MEDIUM SAND
FINE SAND
MAG-NETICS
HIGH IRON FINES
DUST
TAILINGS ~12.5% OF ORE FEED
TRUCK AND RAIL LOADOUT
FLOTATION CIRCUIT
FINE GRIND SILEX CIRCUIT
● - ALTERNATIVE FEED (MARKET DEPENDENT)

NOTE: Dust Collector (not shown) 200 H.P.

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
2.1	Rod Mill - 11.5' x 14'	300
2.2	Ty-Speed Screen - 4' x 10' (8)	3.5
2.3	Vari-Speed Whizzer Classifier	25
2.4	Classifier Draft Fan	170
2.5	Derrick Screen - 4' x 10' (2)	1.5
2.6	Derrick Screen - 4' x 10' (2)	1.5
2.7	Dust Collector	122

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN QFJ
DATE 15-09-84
CHECKED DCS
DATE 20/09/84

PRIMARY GRINDING & CLASSIFICATION
TYPICAL FLOW DIAGRAM

PLANT N° ______

PROJECT No. 20010

from the abrasion of the steel grinding media. The abraded iron in the classifier sand fraction is removed by low intensity magnetic separators. The cleaned sand is screened into various sizes for the glass grade products and for feed to the flotation circuit or fine grind circuits.

The throughput is taken as 40 t/h.

Flotation Circuit

There is no comminution equipment in this circuit. The circuit is described to complete the process.

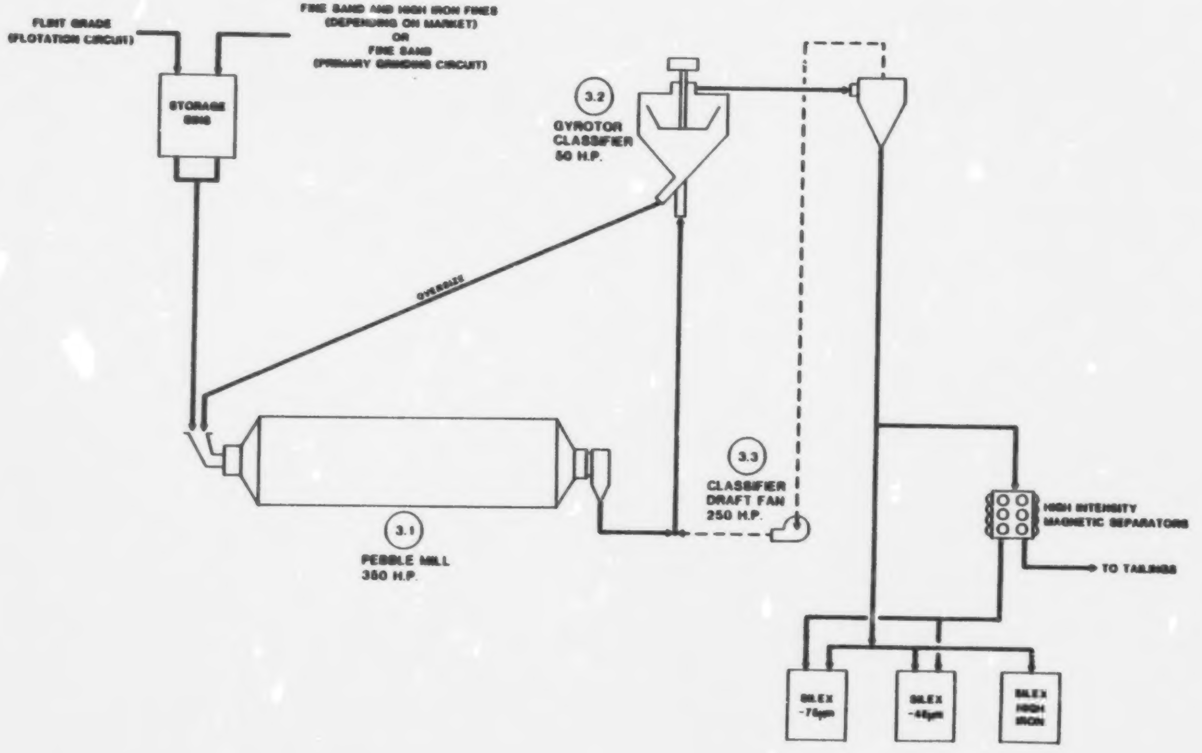
Sized products from the sand circuit can be processed through wet attrition scrubbers, followed by cyclones to remove a slime clay contaminant. The underflow fraction is conditioned with petroleum sulphonate, sulphuric acid, pine oil and xanthate, to remove iron oxides and sulphides in the subsequent flotation circuit. This process reduces the iron content from approximately .05 to .02% Fe_2O_3 and reduces and stabilizes the Al_2O_3 and CaO content. This sand is then filtered, dried and screened into premium glass grade products.

Fine Grinding Circuit

The circuit is illustrated on page 132.

Dry fine sized sand from the previously described circuits is ground using ceramic grinding media in pebble mills operating in closed circuit with air classifiers. Variation in the feed size, feed rate and classifier settings, result in products of various particle sizes. The iron content can be further reduced through the use of high intensity magnetic separators.

The production rate of the circuit is 4.5 t/h for Silex 200 and 2.7 t/h for Silex 325.


FLINT GRADE
(FLOTATION CIRCUIT)
FINE SAND AND HIGH IRON FINES
(DEPENDING ON MARKET)
OR
FINE SAND
(PRIMARY GRINDING CIRCUIT)
STORAGE BINS
3.2
GYROTOR
CLASSIFIER
50 H.P.
OVERSIZE
3.1
PEBBLE MILL
350 H.P.
3.3
CLASSIFIER
DRAFT FAN
250 H.P.
HIGH INTENSITY
MAGNETIC SEPARATORS
TO TAILINGS
SILEX
-75µm
SILEX
-45µm
SILEX
HIGH
IRON

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
3.1	Pebble Mill - 7' x 26'	200
3.2	Gyrotor Classifier	35
3.3	Classifier Draft Fan	170

CANADA CEMENT LAFARGE LTD.
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DATE 20/08/84

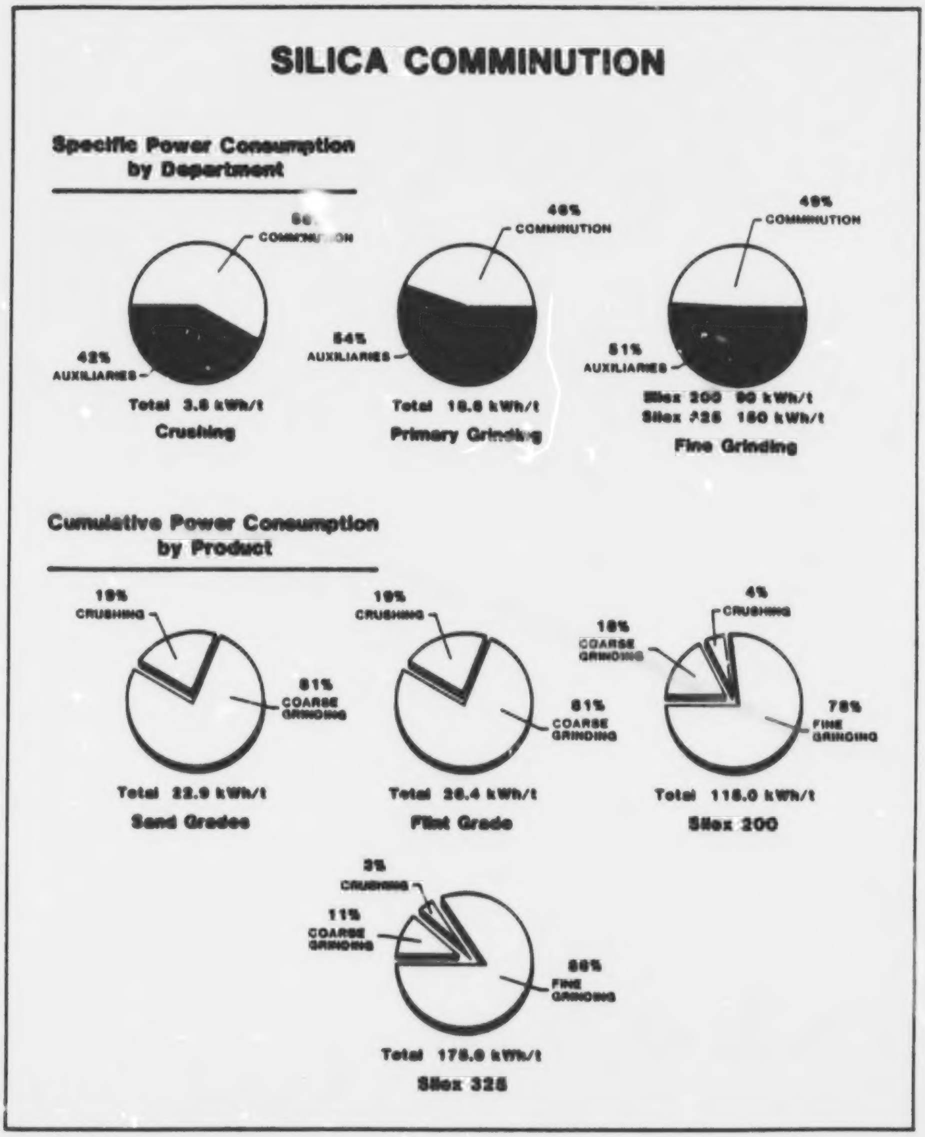
FINE GRINDING
TYPICAL FLOW DIAGRAM

PLANT n° ____________

PROJECT No. **20010**

Results

The energy used in each of the individual three circuits, i.e., crushing, primary grinding and classification, and fine grinding, and cumulative energy used to produce the principal products from these circuits is shown in the following diagram.



The energy per tonne of product for a 1000 tonnes per day process would vary between 30-50 kWh/t and would depend on the product mix, the tonnage rate, humidity and recovery.

The Bond Work Index, expressed as the amount of energy required to grind a tonne of quartzite from infinite size to 80% passing 75 µm, is 26 kWh/Ton. The inefficiencies with pebble mill grinding are evident by the comparison of this theoretical value to the industry consumption of 44 kWh/tonne for comminution of the same product.

Conclusions

The industry has yet to install monitoring and controlling devices required to measure throughput and energy consumption rates. Without this instrumentation, there is little possibility in lowering unit energy consumption.

The industry is operating at 60-80% of capacity and is therefore unlikely to make the necessary commitments to promote the research and development and the capital expenditures required for improved fine grinding and classification equipment.

Recommendations

Investigate ways of producing a ground silica with rounded grains suitable for the foundry industry.

Fine grinding using roller mills and tower mills may become a viable alternative to the industry accepted pebble mills. Deserving consideration is the use of heated air and grinding aids to improve throughput rates and the use of different air classifier designs and multistage classifiers to reduce circulating loads to the grinding mill.

Investigate the use of multi-stage classifiers in a fully instrumented demonstration plant to reduce the amount of overgrinding in the pebble mill air classifier circuit.

REF 434-092
PROCÉDÉ Placdex® PROCESS
MONTREAL, QUÉBEC

TALC

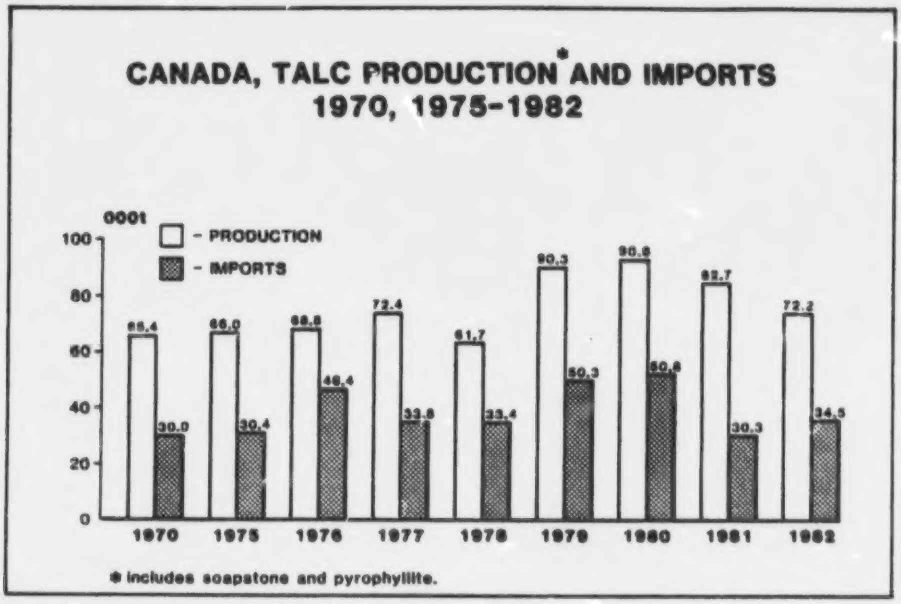
Participating Company

BAKERTALC INCORPORATED

Plant Location

Highwater, Quebec

Talc: High specific power consumption for the micrometer grade but small tonnages



CANADA, TALC PRODUCTION* AND IMPORTS
1970, 1975-1982

* includes soapstone and pyrophyllite.

Sources: Minerals Yearbook Centennial Edition 1981.
Mineral Commodity Summaries 1982, EMR Canada.

Specific power consumption for comminution	**: ground products - 41 kWh/t.**
	pulverized - 248 kWh/t.

Estimated industry power* consumption for comminution 1982 : 6,000,000 kWh.

Background

The earliest activity in the Canadian talc industry occurred in the 1870's. Since that time numerous deposits have been discovered and some have been worked to varying degrees. Currently, talc is mined by four companies in Canada, two in Quebec and two in Ontario.

Most talc imports are from the United States and are high-quality, high-value materials. It is expected that imports will be replaced somewhat by domestic products as capacity for producing higher grades increases.

---

* Based on a ground to pulverized product ratio of 60:40.

Products and Uses

Talc is used mainly as a filler in cosmetics, ceramics, paint, paper, plastics and rubber. Talc products are subject to increasing demands for high purity and quality.

The chemical composition of a typical, relatively high grade industrial talc is presented in the following table.

CHEMICAL ANALYSIS OF INDUSTRIAL TALC
(%)

SiO_2	62.65
Al_2O_3	0.31
Fe_2O_3	-
CaO	Trace
MgO	30.23
$Na_2O + K_2O$	0.20
LOI	4.95
H_2O	4.87
CO_2	0.27

Generally, chemical composition is important insofar as it affects the physical properties. Desirable properties in talc are whiteness, softness and smoothness, coverage, good luster, high "slip", and chemical inertness. Pure talc remains undecomposed in most acids. Chemical composition is controlled by selective mining and by beneficiation during processing.

Talc product fineness is important. Most applications require talc to be -45 µm. The specification for paint is 99.8 to 100 percent -45 µm while, for wall tile, the requirement is 90 percent -45 µm.

Talc sold as paper filler generally meets an average particle size of less than 5 µm and may sometimes be less than 1 µm.

The Production Process

Processing of talc includes crushing and drying talc ore and subsequent fine grinding to product specification. Ground ore may also be subjected to a flotation process to remove impurities. Pulverizing the flotation product can give a super-fine talc for special applications. A typical process flowsheet is shown overleaf.

The Role of Comminution

Three comminution steps are involved in talc processing.

Crushing, where mined ore is dried and reduced to a size suitable for feeding to the mill.

Milling, where crushed ore is ground to the specified fineness of some products (-45 µm) or produced as feed for the flotation circuit. Because of the relative softness of talc, a roller mill is well suited to this application.

Pulverizing, where purified talc from flotation is ground into a superfine product of about 1 µm average particle size. Because of the extreme fineness involved, specialized grinding equipment is required.

Comminution at Bakertalc

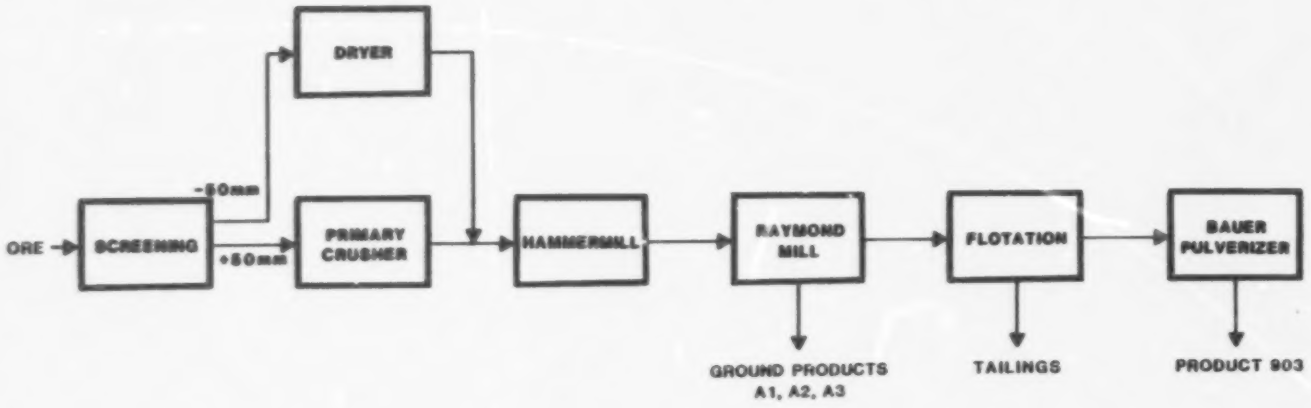
The crushing and grinding circuits

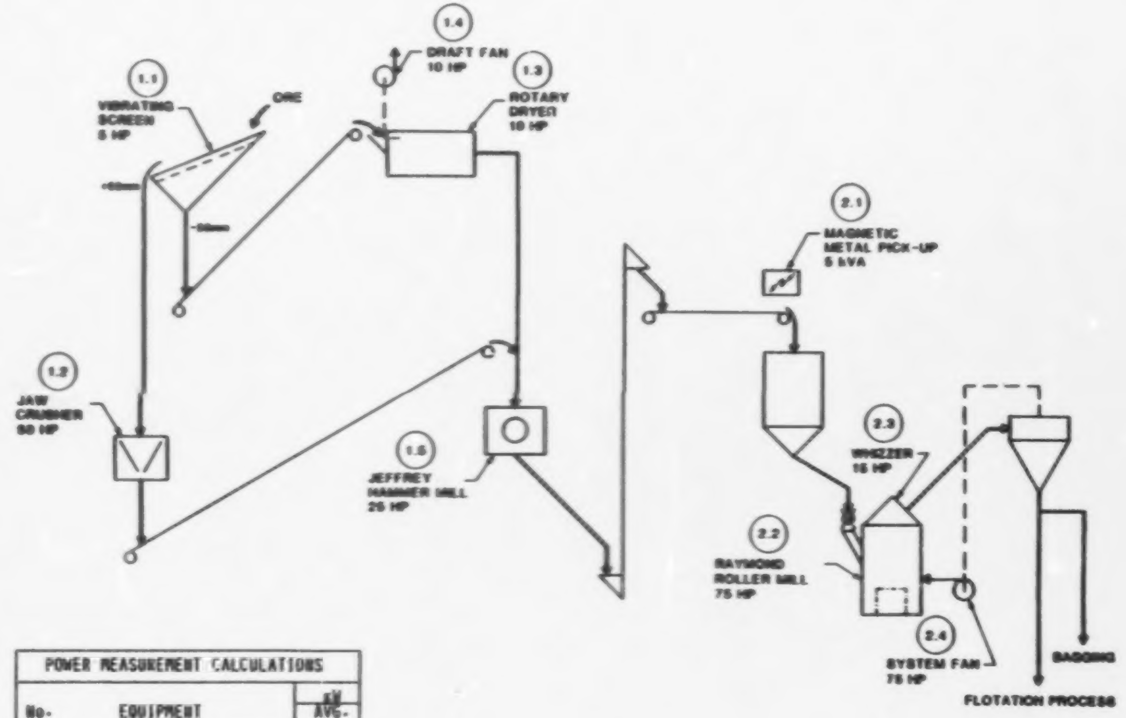
The crushing and grinding circuits are shown schematically on page 139. Rated power (HP) and average power demand (kW) in operation of the various equipment is summarized on the sketch.

The **production rate** of the crushing circuit was estimated to be 23.6 t/h.

TALC PROCESS FLOW SHEET

BAKERTALC, INCORPORATED
Highwater, Quebec


ORE
SCREENING
-50mm
+50mm
DRYER
PRIMARY CRUSHER
HAMMERMILL
RAYMOND MILL
GROUND PRODUCTS A1, A2, A3
FLOTATION
TAILINGS
BAUER PULVERIZER
PRODUCT 903


1.1
VIBRATING SCREEN
5 HP
ORE
+50mm
-50mm
1.2
JAW CRUSHER
50 HP
1.4
DRAFT FAN
10 HP
1.3
ROTARY DRYER
10 HP
1.5
JEFFREY HAMMER MILL
25 HP
2.1
MAGNETIC METAL PICK-UP
5 kVA
2.2
RAYMOND ROLLER MILL
75 HP
2.3
WHIZZER
15 HP
2.4
SYSTEM FAN
75 HP
BAGGING
FLOTATION PROCESS

POWER MEASUREMENT CALCULATIONS

No.	EQUIPMENT	kW AVG.
1.1	Vibrating Screen	-
1.2	Jaw Crusher	10.0
1.3	Rotary Dryer	2.8
1.4	Draft Fan	2.6
1.5	Jeffrey Hammer Mill	7.0
2.1	Magnetic Metal Pick-Up	-
2.2	Raymond Mill	
	Product A1	27.5
	Flotation Feed	22.0
2.3	Whizzer	
	Product A1	8.0
	Flotation Feed	2.5
2.4	System Fan	
	Product A1	56.5
	Flotation Feed	51.0

CANADA CEMENT LAFARGE LTD.
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CRUSHING AND GRINDING
FLOW DIAGRAM

PLANT N° BAKERTALC – HIGHWATER, P.Q.

PROJECT No. 20010

Particle size. Feed material to the crushing circuit was observed to have the following size characteristics:

- Maximum : 300 mm
- Average : 150 - 200 mm
- Minus 5 mm : 40%

Crushing circuit product was found to be minus 63 mm with 75% passing 19 mm.

Grindability testing on a sample of crushed talc ore resulted in a Bond Work Index of 8.35 kWh/T and a Hardgrove Index of 93, indicating a relatively soft material.

Production rate of the Raymond mill varies depending on the material being produced.

- Flotation Feed : 5.0 t/h
- Product A1 : 2.3 t/h
- Product A3 : 1.0 t/h

The **particle size distributions** of Raymond mill products are shown in the following table:

SIZE (μm)	% PASSING		
	FLOTATION FEED	A1	A3
100	98.5	99.0	99.5
70	93.0	97.0	99.0
50	79.5	93.5	99.0
40	70.5	87.0	97.5
20	43.0	34.5	82.0
10	20.0	25.5	35.5
6	10.5	13.5	16.5
2	2.0	3.0	4.0

Pulverizing

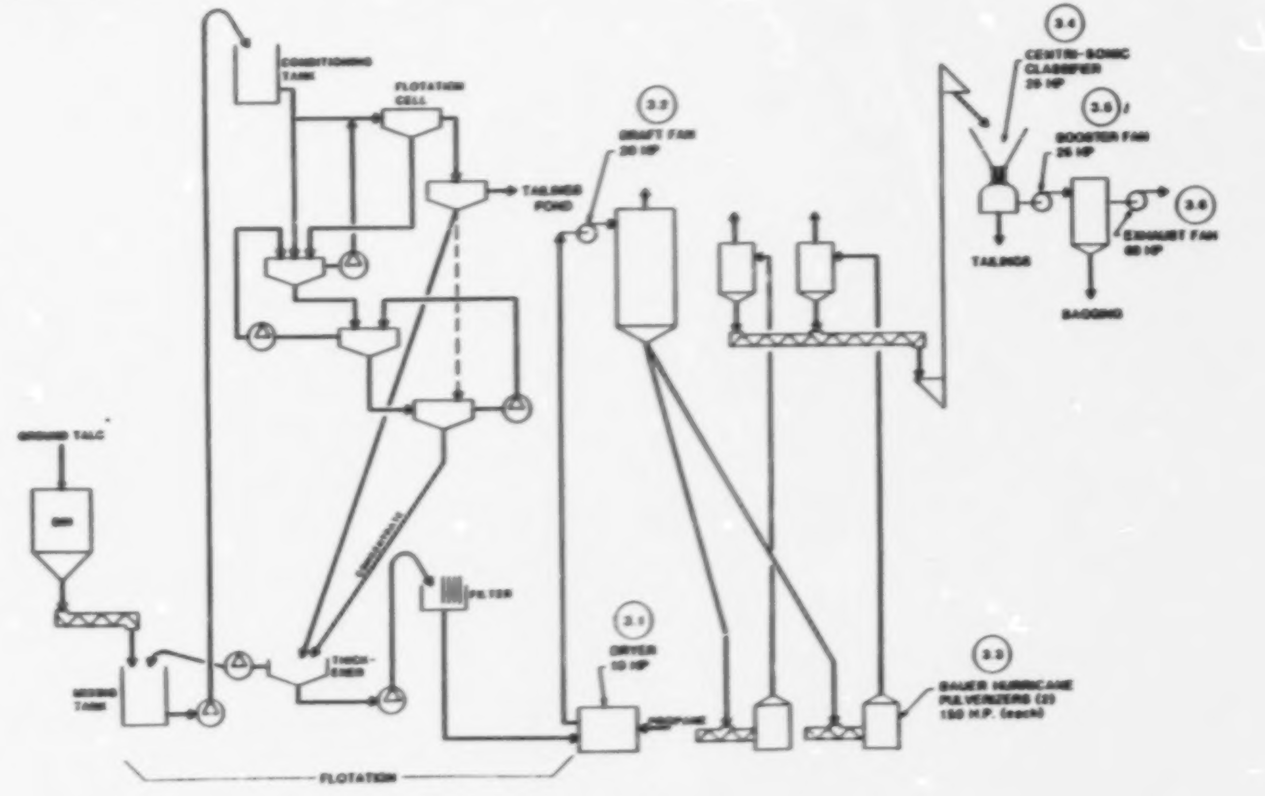
The circuit is shown schematically on page 142. Power demand levels are summarized on the sketch.

The flotation circuit, also shown in the diagram, involves no comminution and is shown only to complete the process. Talc is separated from impurities by adhering to froth bubbles in a talc-water slurry. The product is then filtered and dried. The high iron waste product is pumped to tailings.

The **production rate** of the two pulverizers combined was 0.9 t/h as determined from plant records.

The **particle size distributions** of the pulverizer circuit feed and product are summarized in the following table.

SIZE (µm)	% PASSING	
	FEED	PRODUCT 903
100	100	-
70	97.5	100
50	88.0	99.5
40	79.0	99.5
20	51.0	99.0
10	23.0	94.0
6	10.5	69.0
2	1.5	5.0


GROUND TALC
MIXING TANK
CONDITIONING TANK
FLOTATION CELL
TAILINGS POND
THICKENER
CONCENTRATE
FILTER
FLOTATION
3.1
DRYER
10 HP
PROPANE
3.2
DRAFT FAN
20 HP
3.3
BAUER HURRICANE
PULVERIZERS (2)
150 H.P. (each)
3.4
CENTRI-SONIC
CLASSIFIER
20 HP
3.5
BOOSTER FAN
25 HP
3.6
EXHAUST FAN
60 HP
TAILINGS
BAGGING

POWER MEASUREMENT CALCULATIONS		
No.	EQUIPMENT	kW AVG.
3.1	Dryer	2.8
3.2	Draft Fan	10.7
3.3	Bauer Hurricane Pulverizer (2) - B1 B2	 67.5 75.5
3.4	Centri-Sonic Classifier	6.0
3.5	Booster Fan	9.6
3.6	Exhaust Fan	22.3

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MONTREAL

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DATE [illegible]

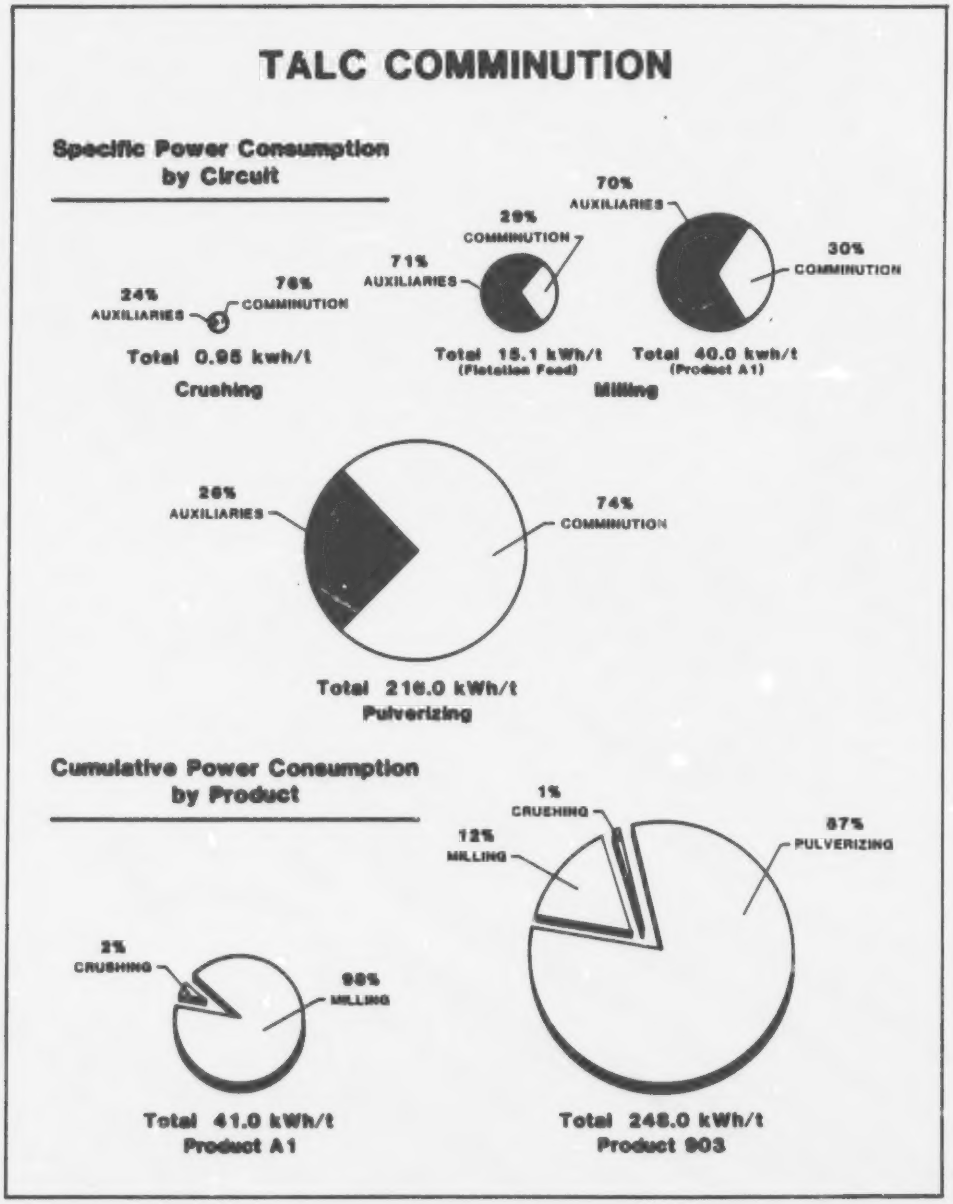
FLOTATION AND PULVERIZING
FLOW DIAGRAM

PLANT AT BAKERTALC - HIGHWATER, QUE.

PROJECT No. 20010

Results

The specific energy consumption of the crushing and grinding circuits and cumulative consumption of finished products are depicted in the following diagrams.



The progression of consumption through the process can be seen with higher specific consumption required for finer grinding, rising from 41.0 kWh/t for product A1 (-45 µm) to 248.0 kWh/t for product 903 (-20 µm).

The cumulative consumption for product 903 allows for a 50% yield in flotation. The results demonstrate the importance of operating the pulverizers efficiently. Consumption in primary crushing and drying is very low in all respects.

A relatively small proportion of Raymond mill consumption is made up of comminution energy. Most of the auxiliary energy is consumed by the mill system fan. The low proportion of comminution energy in flotation feed and A1 may be accounted for by the easy grindability of talc.

Conclusions

The Hurricane mill motors were observed to be operating considerably below installed capacity. Increasing the loading of these motors could mean energy savings for this high-consumption area of the process. However, increased feed rate to the pulverizers may result in reduced grinding efficiency and more tailings generated from the classifier. Process studies may serve to optimize this part of the process.

Recommendation

Despite the relative softness of talc, energy consumption for comminution operations, especially for micrometer grade, is high and studies should be directed towards grinding talc in other types of mills.

The minerals are shown below in two different rankings. One is based on annual consumption for comminution and auxiliaries. The figures are derived from typical annual production volumes and specific energy consumption as directly determined during the Phase I data collection. The other ranking is based on average specific energy consumption for products. The averages are weighted depending on the split among the various products for each mineral.

MINERAL RANKING

Industry Comminution Power Consumption		Weighted Average Comminution Power Consumption by Product	
Mineral	kWh/y x 10^6	Mineral	kWh/t *
Cement	570	Mica	290
Asbestos	186	Asbestos	220
Limestone	98	Talc	125
Gypsum	40	Cement	76
Potash	40	Nepheline Syenite	35
Silica	35	Silica	19
Nepheline Syenite	20	Gypsum	18
Lime	6	Potash	6
Talc	6	Lime	2.8
Mica	3	Limestone	2.5

* Weighted average based on product split.

The difference in ranking between the two tables is a result of the size of the respective industries. Limestone, for example, has a low average product consumption since most product is sold as crushed aggregate. However, it ranks high in industry consumption, due to the size of the industry. In contrast, mica, with the highest product consumption, falls at the bottom of the list in industry consumption because of low production volume. Product consumption for cement, combined with relatively high production volumes, makes cement a large consumer of energy for comminution in the industrial minerals sector.

The next table compares power consumption by comminution circuit for each mineral's finest product. The circuit in question represents the final processing stage for that product and, generally, has the highest power consumption of all process stages.

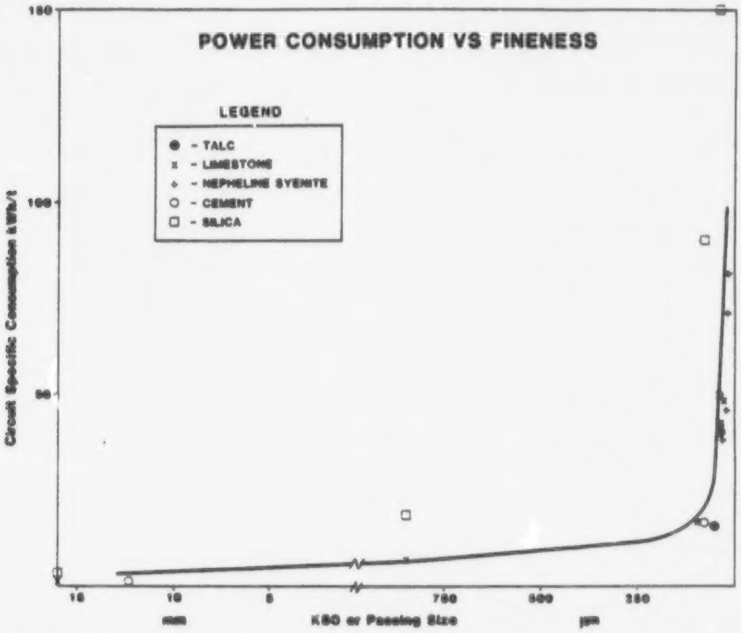
FINE GRINDING CIRCUIT CONSUMPTION

Mineral	Bond Grindability kWh/Ton	Fineness		Circuit Consumption kWh/t	Circuit
		Feed	Product		
Mica	42	-1.7 mm	-45 µm	488	Fluid Energy Mill
Talc	8	80%-41 µm	90%-7 µm	216	Pulverizer
Silica	26	-850 µm	-45 µm	150	Pebble Mill
Asbestos	N/A	N/A	N/A	101	Aspiration
Nepheline Syenite	14	-600 µm	80%-8 µm	82	Pebble Mill
Cement	12	-25.4 mm	80%-40 µm	50	Ball Mill
Limestone	8	80%-40 µm	80%-22 µm	48	Pebble Mill
Gypsum	10	80%-41 mm	80%-83 µm	17	Roller Mill
Lime	4	80%-28 mm	80%-2.4 mm	2.3	Hammer Mill
Potash	14	N/A	-3.35 mm	1.9	Hammer Mill

N/A Not available.

The finenesses shown are those of the feed to the final stage and the product. Where possible, the fineness is reported as the 80% passing size to coincide with the Bond Index which is the energy required to reduce the material from infinite size to 80% passing 75 µm. The energy consumption can be related to the grindability and the degree of size reduction. For a low grindability index and relatively coarse product, e.g. lime, the energy consumption is very low.

The relationship between fineness and energy consumption for a number of minerals is shown in the following figure.



For each mineral, the fineness and power consumption of the intermediate stages and final product were plotted. The fineness is 80% passing size except for silica which is passing size. The energy consumption is seen to increase gradually to 100 μm. As the fineness increases beyond that point, consumption rises very rapidly.

Representative power consumption figures for crushing and grinding are shown below.

POWER CONSUMPTION BY CIRCUIT

Process	Typical Product Size	Typical Power Consumption
Crushing	30 mm	1.5 kWh/t
Grinding	-100 μm -45 μm	40 kWh/t 150 kWh/t

As expected, crushing uses considerably less power than grinding, and power consumption in grinding increases markedly with fineness.

The circuit specific energy consumption for all the minerals are summarized in the next table. They are broken down to show the proportion of auxiliary and classification energy. Classification devices range from single or multi-deck screens in coarse grinding circuits to air sifters, air separators, and vari-speed whizzers in fine grind circuits. Generally, the energy requirement for classification is higher in circuits involving high fineness.

CIRCUIT SPECIFIC ENERGY CONSUMPTION

MINERAL	MATERIAL	PASSING SIZE	K80	CLASS. kWh/t	%	AUX. kWh/t	%	TOTAL kWh/t
Talc	Crushed Ore	63 mm	21 mm	0	0	0.2	24	1
	Product A1	100 µm	35 µm	3.5	9	28	70	40
	Flotation Feed	106 µm	50 µm	0.5	3	11	71	15
	Product 903	70 µm	7 µm	6.7	3	57	26	216
Lime	Crushed Stone	50 mm	28 mm	0.1	8	0.4	51	0.8
	3/16" Lime	6.7 mm	2.4 mm	0.5	20	1.5	66	2.3
	Steelworks Lime	N/A	N/A	0.2	100	0.2	100	0.2
	Hydrated Lime	N/A	N/A	0.1	53	0.1	53	0.2
Limestone	Crushed Stone	50 mm	16 mm	0.1	6	0.6	40	1.5
	Agricultural Stone	3.4 mm	850 µm	0	0	0.2	3	6.6
	Filler	300 µm	92 µm	0	0	1.5	9	17
	Product 452	50 µm	26 µm	2.6	6	17	40	42
	Product 461	45 µm	22 µm	3	6	25	53	48
Nepheline Syenite	Crushed Ore	31.5 mm	12.5 mm	0	0	1.6	69	2.3
	Exolon Feed	600 µm	N/A	0.3	4	0.3	4	5.8
	Crest	75 µm	26 µm	3.9	9.8	3.9	9.8	40
	Peak	75 µm	20 µm	1.6	3.5	1.6	3.5	46
	Apex 400	25 µm	13 µm	26	100	26	100	26
	Apex 700	45 µm	8 µm	36	100	36	100	36
Potash	Crushed Ore	1.7 mm	1 mm	0.04	2.9	0.04	2.9	1.4
	Pink Products	3.4 mm	N/A	1.1	55	1.1	55	1.9
Asbestos	Crushed Ore	133 mm	N/A	0.01	2.5	0.1	27	0.5
	Dry Ore	30 mm	N/A	0.2	8	1.2	56	2.2
	Mill Rock	N/A	N/A	0.5	13	0.5	14	3.5
	Fibre	N/A	N/A	—	—	101	100	101
Cement	Crushed Stone	20 mm	12.3 mm	0.2	4.7	0.3	23	1.3
	Raw Mix	600 µm	78 µm	1	6.3	2.3	14	16
	Cement	83 µm	40 µm	3.2	6.4	4.6	9.2	50
Mica	Crushed Ore	1.7 mm	1.4 mm	0.2	4.7	2.3	50	4.6
	Delaminate	1.7 mm	N/A	16	19	55	69	80
	FE Product	45 µm	N/A	4.1	0.8	17	3.5	488
Gypsum	Crushed Ore	75 mm	41 mm	0.01	0.7	1.3	87	1.5
	Ground Gypsum	330 µm	83 µm	0.3	1.7	7.9	47	17
Silica	Crushed Ore	16 mm	N/A	0.05	1.4	1.6	42	3.8
	Ground Sand	850 µm	N/A	6.5	35	10	54	19
	Silex 200	75 µm	N/A	7.8	8.6	46	51	90
	Silex 325	45 µm	N/A	13	8.6	76	51	150

N/A Not available.

Cumulative energy for the finished products is summarized below.

PRODUCT CUMULATIVE ENERGIES				
MINERAL	PRODUCT	PASSING SIZE	K80	kWh/ tonne
Talc	Product Al	100 µm	35 µm	41
	Product 903	70 µm	7 µm	248
Lime	3/16" Lime	6.7 mm	2.4 mm	3.9
	Steelworks Lime	N/A	N/A	1.8
	Hydrated Lime	N/A	N/A	3.6
Limestone	Crushed Stone	50 mm	16 mm	1.5
	Agricultural Stone	3.4 mm	850 µm	6.6
	Filler	300 µm	92 µm	17
	Product 452	50 µm	26 µm	42
	Product 441	45 µm	22 µm	48
Nepheline Syenite	Glass Grade	600 µm	N/A	16
	Crest	75 µm	26 µm	55
	Peak	75 µm	20 µm	66
	Apex 400	25 µm	13 µm	92
	Apex 700	45 µm	8 µm	102
Potash	Pink Products	3.4 mm	N/A	6.1
Asbestos	Fibre	N/A	N/A	223
Cement	Cement	83 µm	40 µm	76
Mica	"Z" Product	1.7 mm	1.4 mm	4.6
	"S" Product	1.7 mm	N/A	85
	"FE" Product	45 µm	N/A	573
Gypsum	Ground Gypsum	330 µm	83 µm	18
	Stucco	330 µm	83 µm	21
Silica	Sand Grade	850 µm	N/A	23
	Flint Grade	850 µm	N/A	26
	Silex 200	75 µm	N/A	115
	Silex 325	45 µm	N/A	175

N/A Not available.

Refining process and the associated generation of waste material contributes to increased product specific energy since larger volumes of unbeneficiated material must be processed per unit of finished product. Of all Phase I minerals, only limestone involved no beneficiation. Process yields ranged from 83% for mica processing to 33% for potash. A very low yield was encountered in asbestos processing where asbestos fibre comprises only 5.5% of dry ore.

COMPUTERIZED DATA BASE

The data base includes all Phase I minerals. For each mineral, the name of the participating company and the location of the plant that was visited, are noted. The process information deals with individual circuits. In each case, the circuit is identified, followed by an equipment list, power ratings and measured kilowatts while in operation. Material grindability indices are presented, along with particle size data on process streams. The calculated circuit specific energy consumption is included.

The final entry for a given mineral involves cumulative specific energy consumptions for all finished products. A brief narrative outlines the calculation of cumulative consumption, indicating process yield factors and other relevant information.

All minerals follow the same general format of the following data base sample.

The data file is in place in the CANMET computer system. For information, contact EMR, Office of Technology Transfer.

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********************
       GYPSUM
********************

COMPANY/PLANT: DOMTAR CONSTRUCTION MATERIALS LTD.  CALEDONIA, ONT.
DATE MEAUSUREMENTS DONE: FEBRUARY 1984

NUMBER OF FINISHED PRODUCTS=   1

NUMBER OF CRUSHING CIRCUITS=   1
NUMBER OF GRINDING CIRCUITS=   1
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```
          GYPSUM
      CRUSHING CIRCUIT #  1
      *********************

      CIRCUIT NAME/MAT. TYPE:       ORE CRUSHING AND DRYING

                                   EQUIPMENT LIST
                                   --------------

                      EQUIPMENT                           MOTOR             OBSERVED KW
  NO.              TYPE/MAKE/MODEL                  HP    VOLTS   AMPS    MAX    MIN    AVG.

  1.1   SIMPLICITY FEEDER - GRIZZLY                 30    550     32       8.5    8.5    8.5
  1.2   JAW CRUSHER                                 40    550     41      10.1   10.1   10.1
  1.3   WOBBLER FEEDER                              10    550     10       2.1    2.1    2.1
  1.4   SYMONS CONE CRUSHER                         60    550     66      29.7   29.7   29.7
  1.5   ASPIRATION FAN                              10    575     11.5    10.4   10.4   10.4
  2.1   ORE DRYER (GAS)                             50    575     48      21.7   21.7   21.7
  2.2   DRYER I.D. FAN                              60    575     57      26.3   26.3   26.3

      BOND WORK INDEX=                10.32
      HARDGROVE INDEX=                61.00

      OPEN    CIRCUIT

  SAMPLES:

   1 - CIRCUIT FEED
   2 - PRIMARY CRUSHER PRODUCT
   3 - SECONDARY CRUSHER FEED
   4 - CRUSHING CIRCUIT PRODUCT  210 T/H
       DRY ORE  41 T/H

                          SIZE DISTRIBUTIONS (% PASSING)
                          ------------------------------

                  UM      1       2       3       4
                300000   100
                150000    80     100     100
                100000            85      93
                 75000                    80     100
                 50000    40      60      20      90
                 38000                            80
                 25000                            60
                 19000                            50
                 12500                            40
                  4750                            20

      CIRCUIT PRODUCT SPECIFIC POWER CONSUMPTION (KWH/T)
      -------------------------------------------------

      COMMINUTION:     0.1900E+00
      AUXILIARIES:     0.1270E+01

      TOTAL:           0.1460E+01 KWH/T
```

```
          GYPSUM
        GRINDING CIRCUIT # 1
        $$$$$$$$$$$$$$$$$$$$$$

        CIRCUIT NAME/MAT. TYPE:       GYPSUM GRINDING

                                 EQUIPMENT LIST
                                 --------------

                   EQUIPMENT                       MOTOR              OBSERVED KW
NO.            TYPE/MAKE/MODEL                HP   VOLTS  AMPS   MAX    MIN    AVG.

2.3  RAYMOND ROLLER MILL 6000   #1           150   550   140    135    135    135
                                #2           150   550   140    118    118    118
                                #3           150   550   140    115    115    115
2.4  WHIZZER CLASSIFIER         #1            10   550    11.2    3.7    3.7    3.7
                                #2            10   550    11.2    3.3    3.3    3.3
                                #3            10   550    11.2    4.5    4.5    4.5
2.5  MILL FAN                   #1           125   550   116     95.2   95.2   95.2
                                #2           150   575   145     96.3   96.3   96.3
                                #3           125   550   116    103    103    103
2.6  MILL DUST COLLECTOR                      60   575    57     17.6   17.6   17.6

       BOND WORK INDEX=              10.32
       HARDGROVE INDEX=              61.00

       OPEN    CIRCUIT

SAMPLES:

  1 - MILL FEED
  2 - MILL PRODUCT  41 T/H (3 MILLS COMBINED)

                        SIZE DISTRIBUTIONS (% PASSING)
                        ----------------------------

                          UM      1       2
                        75000   100
                        50000    90.5
                        25000    61.9
                        12500    40.0
                         4750    22.4
                         1180    11.4
                          425           100
                          300     5.7    98.8
                          150     3.8    93.0
                          106            84.5
                           75            78.3
                           45            75.5
                           30            69.5
                           20            63.0
                           10            48.0
                            6            35.0
                            2            13.5

       CIRCUIT PRODUCT SPECIFIC POWER CONSUMPTION (KWH/T)
       ------------------------------------------------

       COMMINUTION:     0.8980E+01
       AUXILIARIES:     0.7920E+01

       TOTAL:           0.1690E+02 KWH/T
```

CUMULATIVE KWH/T OF FINISHED PRODUCTS

SPECIFIC CONSUMPTION FOR CRUSHING AND DRYING IS CALCULATED IN TWO PARTS. ELECTRICAL CONSUMPTION FOR DRYING IS CALCULATED USING THE COMBINED PRODUCTION RATE OF THE RAYMOND MILLS (41 T/H). THE RESULT IS THEN ADDED TO THE CONSUMPTION FOR PRIMARY CRUSHING.

CUMULATIVE SPECIFIC ENERGY INCLUDES CONSUMPTION FROM PRIMARY CRUSHING, DRYING AND MILLING OF GYPSUM. THE REPORTED ENERGY ALLOWS FOR A YIELD OF 89% AT CALCINATION SINCE MOST OF THE CHEMICALLY COMBINED WATER IN THE GYPSUM IS DRIVEN OFF.

SPECIFIC ENERGY IS NOT REPORTED FOR PRODUCTION OF GYPSUM BOARD SINCE QUANTITY OF BOARD IS EXPRESSED AS SURFACE AREA. HOWEVER IT WAS ESTIMATED THAT COMMINUTION CONSUMPTION REPRESENTS ABOUT 5% OF TOTAL EQUIVALENT THERMAL CONSUMPTION FOR BOARD PRODUCTION. THE MAJORITY OF THERMAL CONSUMPTION IS FOR DRYING OF THE BOARD AFTER FORMING.

PRODUCT	COMMINUTION	AUXILIARIES	TOTAL
PLASTER	0.1030E+02	0.1030E+02	0.2060E+02

SUMMARY REPORT - PHASE II

PHASE II - REQUIREMENTS (as defined by CANMET)

Establishment of Monitoring Methodology

A laboratory evaluation of commercially available and experimental instruments and monitoring techniques and systems potentially applicable to real-time monitoring of fine particles in grinding circuits shall be made and either existing equipment shall be selected or modified or new equipment shall be developed for subsequent pilot plant studies or real-time circuit control. It shall also be required to develop a sound sampling strategy and ensure good execution.

The preparation of a detailed technical proposal and cost breakdown for the Phase III work is to be provided as part of this requirement. A preliminary description of the third phase is included below.

Development of Pilot Plant Systems (Description Only)

A pilot closed circuit grinding system would be set up reflecting the best available state-of-the-art technology with respect to the needs of representative industrial minerals comminution. The plant would be instrumented for direct energy measurements and designed to allow modular introduction of experimental control systems and removal of material at various stages of comminution. Selected mineral products would be ground in the circuit with a record of total energy-audit versus operating characteristics being established for each. Monitoring/control systems to optimize the total energy consumption would be developed along with necessary software and hardware for their ultimate introduction into full scale plants. In essence, the pilot plant would become a "test-bed" for evaluating grinding control systems and procedures. Direct energy consumption would be immediately measured by instrumentation, indirect energy consumption would be measured or estimated off-line in parallel experiments related directly to the needs of the product user.

Introduction

The advantages of on-line control of milling circuits has been pointed out in a number of articles[1-4]. This interest in automatic control has given rise to development of a range of different types of equipment for on-line particle size measurement.

Davies[1] has identified 21 classes of equipment, classed on the basis of the principles used to sense and size the particles. This article, and earlier reviews[5] by the same author, describe the equipment in some detail.

Principles used to sense and size particles

1. Image replication and analysis
2. Electrical resistance change
3. Light scattering
4. Light obscuration
5. Light diffraction
6. Optical grating method
7. Beta-ray attentuation
8. X-ray absorption and fluorescence
9. Acoustic interference
10. Ultrasonic attenuation
11. Differential air classification
12. Hydroclone separation
13. Pulsating gas flow
14. Pressure drop in a nozzle
15. Transient and evaporative cooling of a hot wire
16. Impact and momentum measurement
17. Magnetic flux variations
18. Electrostatic ion capture
19. Glow discharge perturbation
20. Automatic sieve methods
21. Correlation techniques

Most of the instruments listed are either not directly applicable to the industrial mineral sector or not sufficiently proven to be regarded as commercially available. Thus, in order to focus the study, we investigated the status of on-line equipment development in North America and Europe. From this investigation, it was decided to direct attention to equipment based on light scattering and diffraction.

In addition, it was decided to study the status of automatic Blaine meters, which give a measurement of specific surface area rather than particle size, but could be used in control of mill circuits, particularly in cement plants.

As representative of light scattering equipment, the Microtrac, marketed by the Leeds and Northrup Company, was chosen because of its degree of development and commercialization in North America.

The Microtrac was evaluated under laboratory conditions. Its accuracy and repeatability were compared to the Sedigraph,* an instrument whose operating characteristics have been established over a long period.

No laboratory evaluation was made of automatic sampling equipment because a range of different types of samplers are commercially available and have been proven under plant conditions.

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* The Sedigraph 5000 is manufactured by Micromeritics Inc., Norcross, Georgia. It employs the sedimentation principle, with particles settling in a proprietary liquid and a beam of x-rays as detector.

Laboratory Comparison of Laser and Sedimentation Particle Size Analysis

The comparison of the two types of instruments was based on cement samples of which the 45 µm size had been determined by wet sieving, and other materials from the comminution study. The 45 µm size has been used as a quality parameter in the cement industry for many years. It has been accurately defined by the industry and by the U.S. National Bureau of Standards using electroformed micromesh sieves and, therefore, is a good reference point for establishing the accuracy of the Microtrac and Sedigraph.

The Microtrac can be used for wet or dry samples but, because of difficulties experienced in getting the dry sampling system to operate satisfactorily and concern about agglomeration of particles in the air stream, the comparison between the two instruments was carried out on slurried samples. Water, with a small quantity of detergent, was used as the dispersing medium for Microtrac samples. A proprietary liquid, Sedisperse A13, was used with the Sedigraph.

Sedigraph

Repeatability

To evaluate the repeatability of the Sedigraph, tests were made on a Portland cement from C.E.R.I.L.H.*, the research centre of the French cement industry.

Results obtained with the French cement are shown in the table overleaf. The particle sizes in the table are chosen to coincide with those detected by the Microtrac.

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* Centre d'Études & de Recherches de l'Industrie des Liants Hydrauliques.

Sedigraph - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	96.5	98.0	97.0	97.0	97.0	98.5	97.3	0.60	2.0
62	93.0	94.0	93.5	91.5	91.0	94.0	92.8	1.07	3.0
44	85.5	85.0	85.5	83.0	81.5	85.5	84.3	1.40	4.0
31	71.5	71.5	71.5	70.5	69.0	73.5	71.3	0.98	4.5
22	60.0	57.0	57.5	56.5	55.5	60.0	57.7	1.43	4.5
16	45.5	44.5	45.0	45.0	44.5	47.0	45.3	0.68	2.5
11	33.5	33.0	33.0	33.5	33.0	36.0	33.7	0.80	3.0
7.8	24.5	23.5	24.0	24.5	24.5	26.5	24.6	0.65	3.0
5.5	17.5	16.5	17.0	18.0	18.0	19.5	17.8	0.75	3.0
3.9	12.5	11.5	11.5	13.0	13.5	14.5	12.8	0.92	3.0
2.8	8.5	7.5	7.0	9.0	9.5	10.0	8.6	0.92	3.0

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The accuracy of the Sedigraph was determined from results obtained on a C.E.R.I.L.H. cement which is used as a standard for particle size analysis.

The results are given below.

Sedigraph - C.E.R.I.L.H. Cement

Cumulative % finer than size shown.

µm	Mean Sedigraph Value (%)	Assigned Value (%)
88	97.3	94.5
62	92.8	89.5
44	84.3	82.0
31	71.3	70.0
22	57.7	57.0
16	45.3	44.5
11	33.7	35.0
7.8	24.6	25.5
5.5	17.8	20.0
3.9	12.8	14.0
2.8	8.6	9.5

A further evaluation of Sedigraph accuracy was made from the 45 µm (#325 mesh fineness) determination on the six Portland cements. The #325 mesh fineness had been determined by wet sieving at ten separate laboratories as part of a Canada Cement Lafarge inter-laboratory program. Sedigraph and #325 mesh results are compared in the following table.

Wet Sieving v. Sedigraph at 45um

Sample No.	#325 (45µm) % Passing	Sedigraph % finer than 45µm
240	94[illegible]	95.2
241	98.1	98.0
277	94.9	94.1
281	86.3	85.8
287	91.1	90.0
294	95.3	95.1

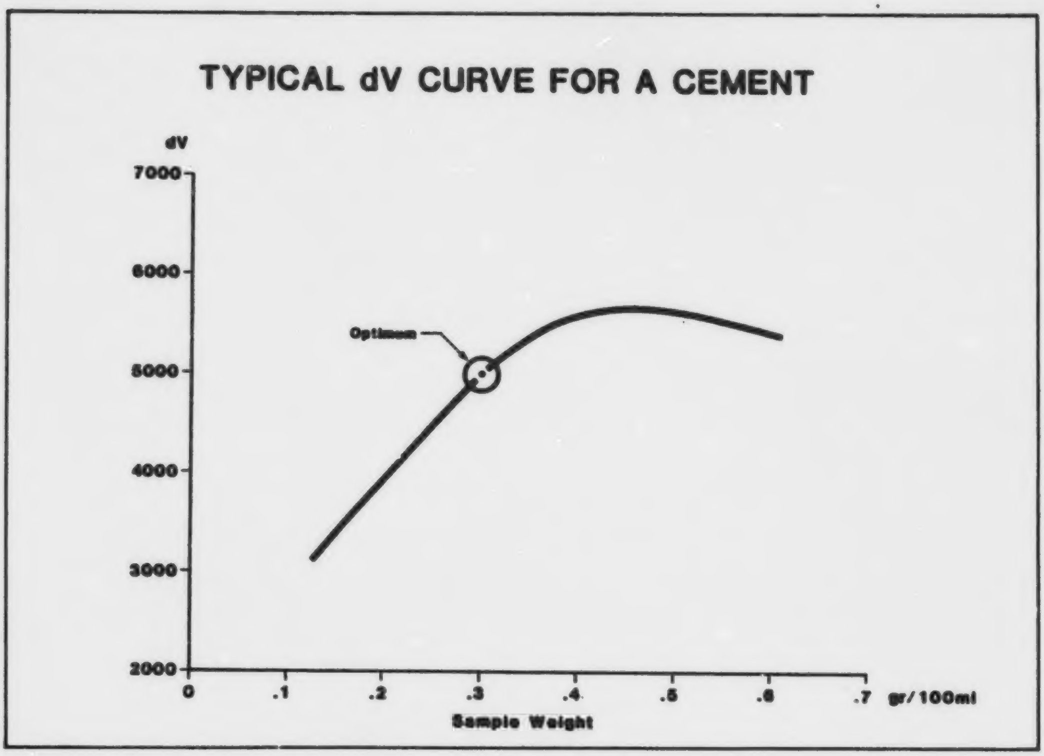
It is concluded from the results that, over the particle size range under study, the Sedigraph has both good accuracy and repeatability.

Microtrac

The Microtrac results are influenced by the weight of sample (as opposed to the Sedigraph which is relatively insensitive to sample weight). The manufacturer stresses the importance of the optimum weight of sample, and the instrument is equipped to indicate this optimum in the form of a number called "dV".

The dV number is defined as "a volume response giving an uncalibrated indication of the amount of particulate matter in the system". With the Microtrac, it is important that sample loading be low enough to keep main-beam attenuation and multiple light scattering at non-critical levels but high enough to achieve good resolution at the diffraction angles involved.

Optimum sample loading is obtained by plotting the dV number against variations in sample weight. The recommended sample weight is that near the peak of the resulting curve. A typical dV curve is shown in the figure below.



Results of dV and optimum loading weights for the six test Portland cements are given belcw. Densities for Portland cements are constant at 3.15 g/cm3.

Optimum Loading and dV for Portland Cements

Sample No.	Surface Area Blaine (cm^2/g)	dV	Optimum Sample Weight (g)
240	5490	.2396	0.15
241	5290	.2483	0.15
277	4500	.4006	0.25
281	2980	.5645	0.30
287	3420	.4518	0.30
294	4010	.3794	0.25

The results indicate that dV and optimum loading weights vary in relation to the surface area of the material in spite of a constant density.

Optimizing the dV response of the Microtrac will be an important parameter in any on-line application where wide ranges of fineness could be found.

Repeatability

Repeatability of the Microtrac for the analysis of a standard cement is demonstrated in the next table, which shows that the variation in Microtrac results is similar to the Sedigraph for the standard cement.

Microtrac - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	100	100	100	100	100	100	100	0.00	0.0
62	98.1	100	99.4	100	99.8	100	99.6	0.52	1.9
44	94.7	98.1	95.8	96.5	96.2	96.7	96.3	0.77	3.4
31	85.7	87.1	87.5	86.1	87.0	85.8	86.5	0.67	1.8
22	71.1	71.0	73.4	72.6	72.0	73.0	72.2	0.82	2.4
16	57.0	58.9	59.1	58.4	58.0	58.3	58.3	0.52	2.1
11	41.2	42.6	42.1	42.2	42.6	42.0	42.1	0.35	1.4
7.8	28.5	29.1	29.9	29.3	28.0	29.5	29.1	0.52	1.9
5.5	17.1	18.4	20.4	18.7	17.6	19.3	18.6	0.88	3.3
3.9	8.6	9.5	10.5	9.8	9.3	10.4	9.7	0.55	1.9
2.8	4.4	4.7	4.4	4.1	4.3	3.9	4.3	0.20	0.8

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The Microtrac results for the standard C.E.R.I.L.H. cement are compared with the assigned values in the following table.

Microtrac - C.E.R.I.L.H. Standard

Cumulative % finer than size shown.

Particle Size (µm)	Mean Microtrac Value (%)	Assigned Value (%)
88	100	94.5
62	99.6	89.5
44	96.3	82.0
31	86.5	70.0
22	72.2	57.0
16	58.3	44.5
11	42.1	35.0
7.8	29.1	25.5
5.5	18.6	20.0
3.9	9.7	14.0
2.8	4.3	9.5

The Microtrac results are considerably higher than the assigned values from 88 to 7.8 µm. Below this particle size, the results are lower than assigned values.

An estimation of Microtrac accuracy was also made by evaluating its performance at the 45 µm size. The following table, comparing wet sieving, Sedigraph and Microtrac results for the six test cements, confirms that the Sedigraph is more accurate for this particle size.

Wet Sieving v. Microtrac at 45 µm

Sample No.	No. 325 (45 µm) % Passing	Microtrac % Finer Than 45 µm
240	94.3	100.0
241	98.1	98.8
277	94.9	97.0
281	86.3	87.5
287	91.1	97.2
294	95.3	94.8

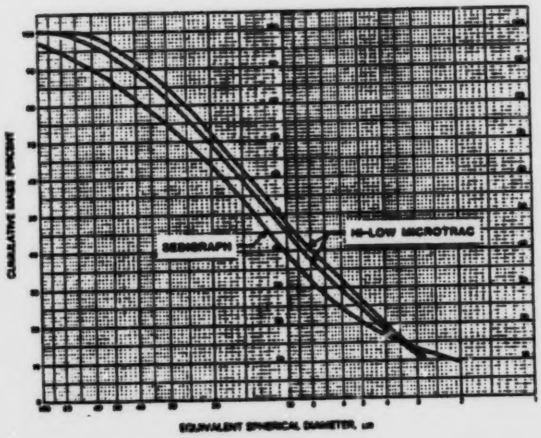
On the average, Microtrac results are consistently higher than those of wet sieving, but not to the extent seen with the standard cement.

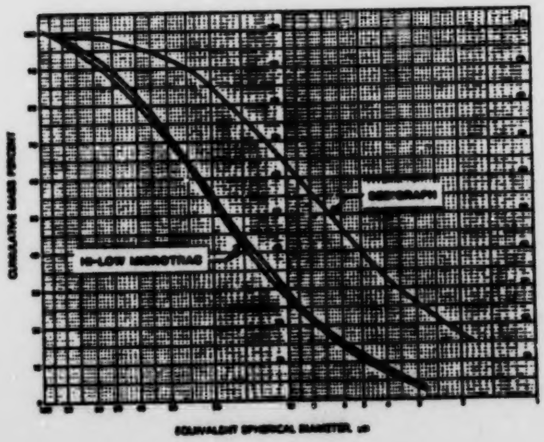
Particle size analysis of non-cement materials

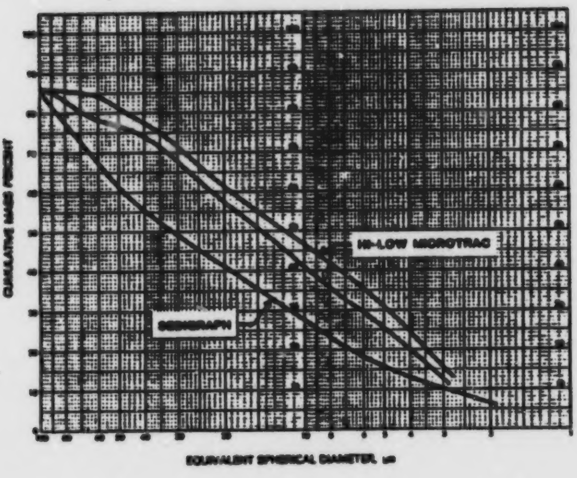
A comparison of the results from the Microtrac and Sedigraph analysis of the following materials

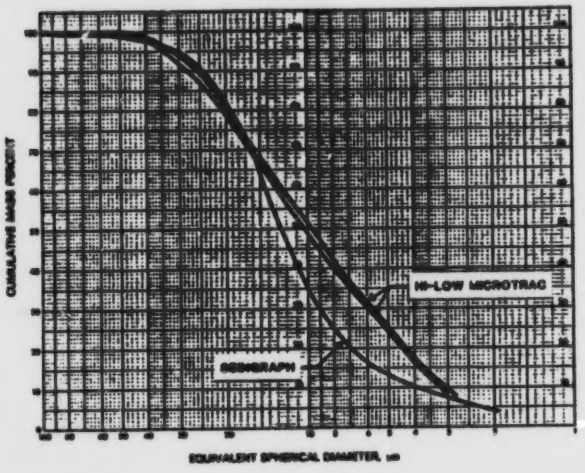
- cement raw mix
- mica
- limestone, limestone (calcite)
- talc
- nepheline syenite

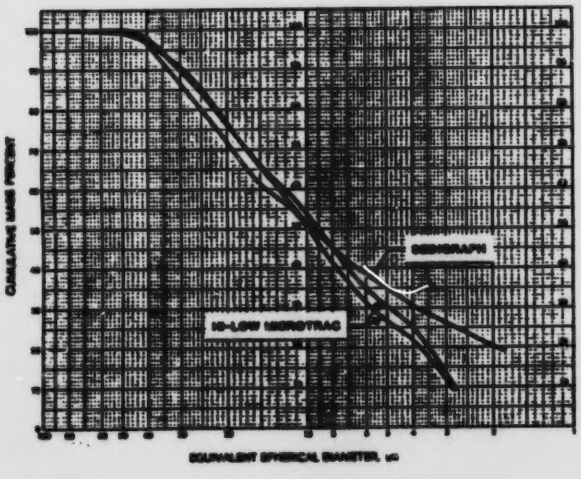
are shown in the graphs below. The "hi-low" Microtrac curves give the range of results obtained from a set of samples.

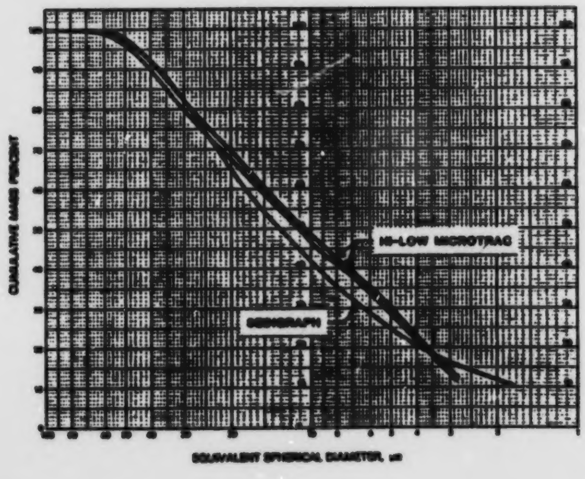

CEMENT RAW MIX


MICA


LIMESTONE


TALC


LIMESTONE - (Calcite)


NEPHELINE SYENITE

For the Portland cement raw mix, composed of a mixture of limestone and shale, No. 325 wet sieving indicated 81.2% passing at 45 µm. The Sedigraph and Microtrac gave 83.8% and 93.0%, respectively. This result is consistent with earlier data indicating that the latter is less accurate at the coarse end of the scale.

The results for the mica sample show the largest difference between the two instruments. The wide difference in results could be attributed to the shape of the particles affecting sedimentation.

There is also considerable difference in results for the Domtar limestone sample. Differences like this are difficult to explain without further exploration, but could be due to poor dispersion in water of the Microtrac samples.

In general, the reproducibility of the Microtrac results for the industrial minerals was found to be within the ±5% range quoted by Leeds and Northrup[9].

On-line Application of Particle Size Analysers

On-line applications of a number of types of particle size analysers are summarized in the table below.

ON-LINE APPLICATIONS			
CLASSIFICATION BASED ON PARTICULATES CONCENTRATION IN THE SENSING REGION	MODE		CURRENT STATUS
	WET	DRY	
I. Low Concentration Methods (single particles)			
- Electrical Conductivity	X		- Restricted to contaminants.
II. High Concentration Methods (5-70% by weight)			
- Hydrocyclone	X		- Tested in plant environment[6].
- Automatic Sieving	X		- Not in current use. Min. 100 um particles.
- Ultrasonic Attentuation	X		- Tested in plant environment[6] (Armco Autometrics).
- Beta-Ray Attentuation	X		- Not in use.
III. Intermediate Concentration Methods (0.1% by weight)			
- Light Diffraction		X	- Cilas; not in current use.
	X	X	- Microtrac: currently installed in a number of locations.
- Differential Air Flow		X	- Metzger & Leschonski's Model: commercialization in process[8].
IV. Air Permeability (Blaine meter)		X	- Japanese development - unknown; presumed abandoned
		X	- Fuller's mid 70's model: abandoned.
		X	- Milltronic's early 70's model: abandoned.
		X	- Holder Bank - Hasler: currently in plant testing.

The first category is applicable to low concentrations of particles and not directly relevant to industrial mill circuits. The high concentration methods were not explored further because they do not appear to be under active development at present.

Of the remaining two categories, laser systems have been tested under plant conditions, a differential air flow method is reported to be ready for commercialization and at least two automatic Blaine meters are installed in plants.

Laser Systems

The Microtrac is the most widely commercialized particle size analyser in this category. In North America, some 400 units are reported to have been sold to a wide range of industries, including explosives, food, chemicals, minerals and oil.

A number of industries, where on-line monitors are installed, were contacted. The applications are shown in the table.

ON-LINE MICROTRAC APPLICATIONS

INDUSTRIES	PLANT & LOCATION	PARTICLE CHARACTERISTICS	MODE	
			WET	DRY
Cement	- Calavares Cement Redding, California, USA	80-90% passing 325 mesh		X
	- Florida Mining Brooksville, Florida, USA			X
	- Lonestar Cement Seattle, Washington, USA			X
	- Blue Circle Industries Greenhithe, Kent, UK			X
Talc	- Talc-de-Luzenac Luzenac - Arièges, France	10-50 µm		X
Minerals (Tailings)	- Lornex Mining Logan Lake, B.C., Canada	2.7-300 µm	X	
Alumina	- Alcoa Tech. Centre Alcoa Centre, Pa, USA	--	-	-
Iron Ore	- Iron Ore Company Newfoundland, Canada	65% passing 44 mesh	X	
	- Bethlehem Steel Bethlehem, Pa, USA	--	X	

The results from the talc and iron ore plants were reported to be satisfactory, while the cement industry and mine tailings still had problems to overcome. The main difficulties cited for the dry mode were control and presentation of the sample in a dispersed form to the laser beam. In the wet mode, daily clean-up of the sample cell was necessary and abrasion was a problem. Very little quantitative data describing the performance of the instruments was available.

In general, some concern was expressed about the ability of the instrument to stand up to the heat, dust and vibration in a plant environment.

Permeability Systems (Blaine meter)

Hasler Frères SA have developed an automatic Blaine meter. One of these meters has been installed at a German cement plant since 1982 and is, according to a Hasler report[10], operating well.

The objectives of the installation were;

1) to insure a constant fineness of the finished cement within a divergence of ± 100 for three different Blaines (3100 - 4300 - 4900 cm^2/g);

2) to have maximum possible output at these finenesses;

3) to reduce the energy consumption of the mill to the minimum;

4) to be adjusted easily to different types of input material;

5) to enable the system to be controlled remotely.

The mill being controlled has two compartments, a 3500 hp motor and an output of about 100 t/h. It is equipped with a Pfeiffer Turbo separator.

Ciments Lafarge France commissioned a Hasler automatic Blaine meter, at a cement plant in Marseilles, in early 1983. No reports on the performance of the equipment are available yet.

The Sedigraph is an accurate instrument, giving good reproducibility of results in the 100 - 2 µm range. Because of the time required to prepare and run samples, it is best suited for a laboratory role. However, it provides a useful reference for evaluating the performance of other instruments.

Laser based instruments of which the Microtrac is the most developed and commercialized in North America, could be used for on-line particle size analysis in the industrial minerals industry, if the problems associated with dispersing the particles and presenting a dry sample of suitable concentration to the sensor can be overcome.

The reproducibility of the Microtrac results is similar to the Sedigraph, but generally gives higher readings.

It can span a wider range of particle sizes, 200 - 2 µm, compared to 100 - 2 µm.

The Microtrac scanning time can be as low as 25 seconds, compared to 25 minutes for the Sedigraph.

The Microtrac has apparently been tried in a number of on-line applications but with limited success.

Automatic Blaine meters are installed in at least two cement plants in Europe. One is reported to have performed satisfactorily since 1982. The other was commissioned in 1984.

The Blaine meter gives a measure of specific surface area rather than particle size and has a slower response time than the Microtrac but could be used for mill circuit control, particularly in the cement industry.

[illegible]
PROCÉDÉ Plasdex® PROCESS
MONTREAL, QUÉBEC

PILOT PLANT PROPOSAL

The task, as originally defined, specified that a detailed technical proposal and cost breakdown for a pilot plant be prepared. However, there are a number of well-equipped R&D organizations in Canada with suitable pilot plant facilities and extensive experience in mineral processing. Therefore, we believe that it would be more economical to conduct a test program in existing facilities, rather than constructing a new pilot plant.

Proposed Test Program

The test program should be designed to integrate the recommendations from this study with the findings of the CANMET survey of opportunities and problem areas in the industrial minerals industry. A report on the survey was published in 1983.*

A summary of the survey results and study recommendations for each of the minerals is shown in the table below and continued overleaf. The survey results apply to overall processing, while the study recommendations are comminution related.

Mineral	Processing Problem Areas Identified in Survey	Comminution Study Recommendations
Asbestos	- Improved screening of damp fibre. - Improved and more efficient separation of fibre at 75 µm. - Separation of mica from asbestos fibre. - Development of techniques for filtering and drying fibre without degradation. - Improved techniques for characterizing and evaluation of fibre. - Development of wet treatment processes for fibre recovery. - Improved screening capacity and life of screens by use of rubber-covered screen grids. - Tendency of damp fibre to adhere to processing equipment. - Improved filtration for asbestos-cement systems.	Develop wet milling technology in order to reduce the power consumed in dust collection in dry milling.
Cement	- Improved crushing of raw limestone to produce finer size material as feed to raw milling circuit. - Grinding of slag cements.	Improve the classification of cement to reduce the amount of coarse and superfine material in the finished product. This represents an opportunity for Canadian manufacturers to develop new equipment or find ways of retrofitting existing classifiers. Test the efficiency of other dry milling systems, for example, tower mills, for grinding clinker.

---

* R.K. Collings & P.R.A. Andrews, CANMET, Report 83-SE.

Mineral	Processing Problem Areas Identified in Survey	Comminution Study Recommendations
Gypsum	- Blasting, crushing, grinding to minimize fines production (minus 10 mm). - Gypsum/anhydrite middling product in heavy media processes. - Crushing of gypsum; although the rock is not hard or abrasive, it is more difficult to crush than many harder rocks; crusher types, sizes. - Study on pelletizing of fines. - Process monitoring and control.	No specific recommendations.
Lime	None reported.	No specific recommendations.
Limestone (Calcite)	- The removal of impurities, e.g., iron and magnesium silicates, by colour sorting, magnetic separation, etc., to enable production of higher grade material for fillers, cosmetics, and pharmaceutical applications.	No specific recommendations.
Mica	- Beneficiation, applicability of magnetic separation, gravity separation, leaching, flotation and air classification. - Mica grinding and delamination to produce a higher aspect ratio flake for use as reinforcing agent in plastics. - Delamination and breakage of ultra-thin flakes in the mixing/dispersion/coupling process. - Classification of mica. - Feasibility of the recovery of quartz, kyanite, staurolite and associated minerals as co-products from Ontario mica deposits.	Test alternative milling systems for delaminating and grinding mica with a view to reduction of the power consumed in the manufacture of fine mica products.
Nepheline Syenite	- Reduction of Fe_2O_3 in hornblende nepheline syenite. - Development of methods of ultra-fine classification, especially in 16 µm range.	Test the efficiency of autogenous milling to reduce the number of comminution stages.
Potash	- Development of dry methods for potash recovery, e.g., electrostatic separation. - Potash flotation; computer control in flotation circuits. - Compaction of potash fines. - Recovery of KCl salts by brine evaporation. - Development of instruments to analyze for KCl. - Loss of potash values to waste salt.	No specific recommendations.
Silica	- Grinding and classification of sandstone, especially tertiary grinding to achieve more effective reduction of sandstone to natural grain size without grain fracture and overproduction of fines. - Beneficiation of sand to glass-sand purity, especially dry beneficiation processes for removal of pyrite and shale. - Reduction of iron in silica sand to 0.005% Fe_2O_3 for optical glass. - Reduction of iron in silica fines to "chemical" standards. - Production of ultra-high purity silica/silicon for silicon chip manufacture. - Reduction of quartzite/sandstone to free impurities; removal of impurities followed by agglomeration for specialty, high-purity uses, e.g., silicon production (probably too costly in view of relatively low price for high purity, lump silica). - Excessive wear on crushing and grinding equipment.	Explore ways of producing a ground silica with rounded grains suitable for foundry use to replace imports.
Talc	- Beneficiation: magnetic separation, gravity concentration, leaching, flotation, air classification. - Removal of iron, chlorite, and dark mineral particles to upgrade and improve brightness of product. - Grinding, particularly wet pebble mill grinding, prior to flotation. - Fine grinding and delamination to 90% minus 5 µm for use in filler applications.	Investigate the use of pebble mills as a more efficient means of grinding superfine products.

So that the pilot plant addresses as far as possible the major issues raised by the survey and the current study, we recommend that the test program be selected from the following topics:

asbestos - investigate wet milling;

cement - improve classification,

- investigate the efficiency of alternative types of mills for clinker grinding;

gypsum - investigate crushing;

mica - test alternative milling systems to produce a higher aspect ratio flake and reduce power consumption;

silica - explore ways of producing a ground silica suitable for foundry use;

talc - investigate alternative mills (for example, pebble mills) as a more efficient means of producing superfine products;

grinding aids - investigate the nature of the bonding forces in particle agglomerates and the effectiveness of commercial grinding aids in dispersing the agglomerates;

crushing and milling - since crushing requires less energy than grinding, seek ways to optimize mill feed preparation in crushing circuits;

particle size monitoring - test the performance of laser particle size monitors and automatic Blaine meters under pilot plant conditions;

circuit control - develop mill circuit control strategies using on-line particle size monitors.

It is recommended that criteria be developed to rank these topics by order of importance, so that a schedule for the pilot plant test program be established.

Cost Estimates

Based upon an estimated cost range of between $25,000 to $35,000 per month for pilot plant testing, the graph on the following page indicates the "available Pilot Plant Months" for a particular budget.

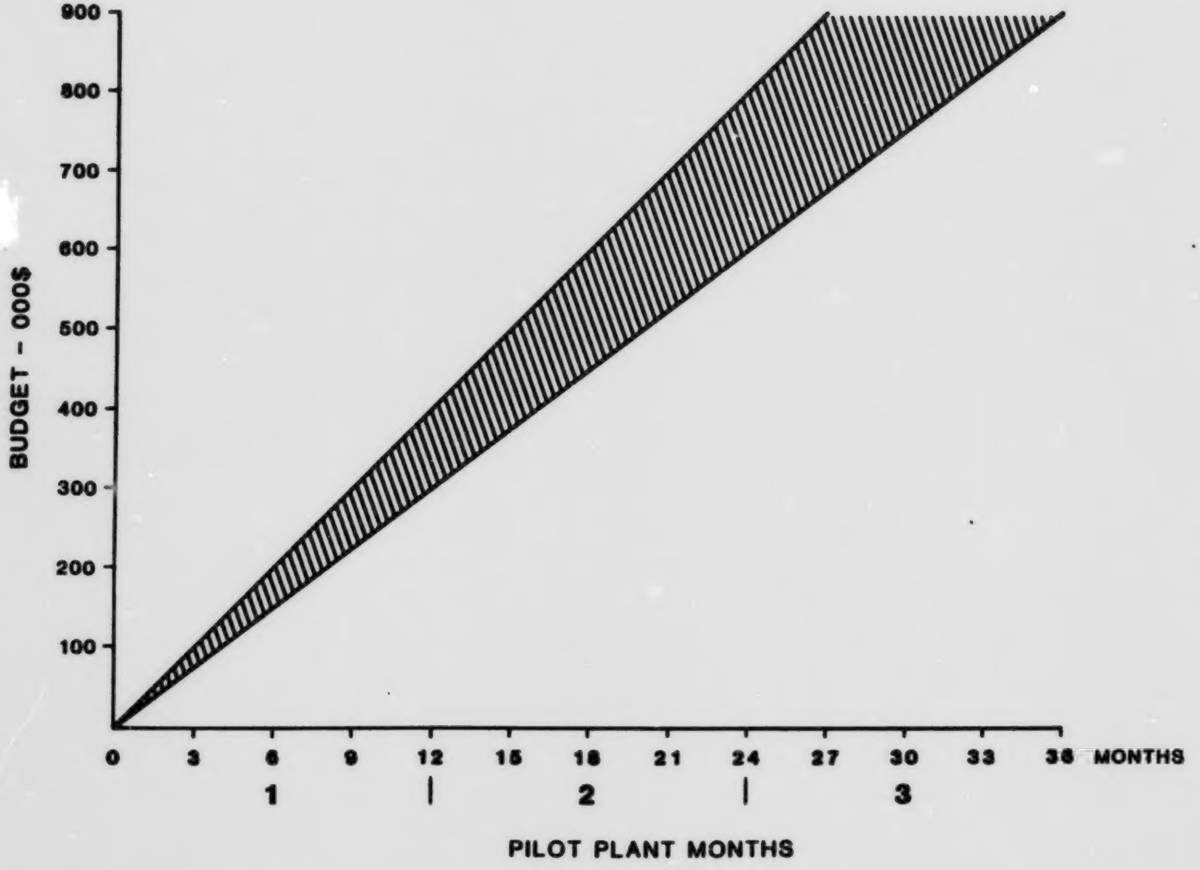
Programs will vary in length as well as importance and, in many cases, be extended. The graph, therefore, provides a source of quick reference to determine funds necessary to cover estimated costs.

As shown, a budget of between $300,000 to $425,000 will be required for the first year, depending on the type and nature of programs scheduled.

Subsequent years can be tailored to conform to available funds.

PILOT PLANT AVAILABILITY GRAPH

$25,000-$35,000 / MONTH COST



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Volume

2

CONTENTS OF VOLUME II

Industry Reviews

Asbestos

Cement

Gypsum

Lime

Limestone

ASBESTOS

REF. 434 175
PROCÉDÉ Plasdex ® PROCESS
MONTREAL, QUEBEC

THE ASBESTOS INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

257 pp

DSS File Number: 23SQ.23440-2-9016A
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MICROMEDIA

TABLE OF CONTENTS

			Page No.
1.	INTRODUCTION		1
2.	COMPANY DESCRIPTION		2 - 5
	2.1	General	2
	2.2	Products	3
3.	PROCESS DESCRIPTION		6 - 22
	3.1	Process Flow	6
	3.2	Crushing	6
	3.3	Drying	11
	3.4	Milling Circuit	15
	3.5	Fibre Grading	19
	3.6	Packaging and Shipping	19
	3.7	Air Handling System	21
	3.8	Quality Control	22
4.	RESULTS & DISCUSSIONS		23 - 32
	4.1	Crushing Circuit	23
		4.11 Electrical Measurements	23
		4.12 Flowrate	24
		4.13 Size Distribution	24
		4.14 Specific Power Consumption	24

TABLE OF CONTENTS
(cont'd)

Page No.

4.2 Drying Circuit 25

4.21 Electrical Measurements 25
4.22 Flowrate 26
4.23 Size Distribution 26
4.24 Grindability Testing 27
4.25 Specific Energy Consumption 27
4.26 Cumulative Power Consumption 28

4.3 Milling Circuit 29

4.31 Electrical Measurements 29
4.32 Flowrate and Size Distribution 29
4.33 Specific Power Consumption 30

4.4 Fibre Grading 31

4.41 Electrical Measurements 31
4.42 Specific Power Consumption 32

5. CONCLUSIONS AND RECOMMENDATIONS 33

5.1 Conclusions 33
5.2 Recommendations 33

APPENDIX - Industry Review
1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Lac d'Amiante du Québec Ltée (L.A.Q.)

Plant Location:

Black Lake, Quebec

The report first introduces the cooperating company. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported, discussed and concluded.

For readers who are not familiar with the Asbestos industry, an appendix entitled "Industry Review" has been added.

Details concerning data collection and field work, as well as other raw data, are available in the working papers.

2. COMPANY DESCRIPTION

Lac d'Amiante du Québec Ltée, (LAQ) was originally known as Lake Asbestos of Quebec Ltd. It was formed in 1952 as a subsidiary of ASARCO Inc., a leading international non-ferrous mining, smelting and refining company.

2.1 General

The company's ore bodies lay under a lake located near the town of Black Lake, Quebec, approximately 113 km southwest of Quebec City. The Crown granted mining rights in 1948 to United Asbestos Corporation Ltd., who conducted the initial exploration program.

The exploratory results were presented to LAQ, which decided to investigate the property further. In 1954, a final agreement between LAQ and United Asbestos was reached; the property would be developed on a profit-sharing basis.

The company re-routed a river, a major highway and a railroad. Then drained the lake, built basins and dams, and removed more than 55 million cubic meters of earth to reach the asbestos ore at the bottom of the 4km-long lake.

LAQ acquired another mine, The National, in 1973. The mine and mill, located near Robertsonville, Quebec, were in operation when purchased.

The LAQ operation employs 750 people; 650 union hourly and 100 staff, working 3 shifts per day six days per week to mine 50,000 tonnes of ore per day.

In Canada, the company is currently second in finished product capacity and third in the amount of ore mined.

The estimated future life of the quarry is 20 years, which would require that the mine be deepened another 90 meters.

2.2 Products

The LAQ milling operation at Black Lake, Québec, produces 50 or more different product grades. Additional grades can be produced, as the primary difference between grades is fiber length distribution. Other important characteristics are degree of openness, cleanliness and strength. Consumers demand uniformity of the product, which is controlled during fibre production. Tests are made on samples taken at frequent intervals in the fibre circuit. As the results are analysed, adjustments to the grading circuit may be made.

Normally, the fibre is contained in bins before being fed into the packing machines. A sample of each bag and a composite sample per tonne of product are tested to ensure the quality of the final shipment.

The Quebec asbestos industry classifies milled asbestos fibres into 5 main groups according to fibre length distribution. These are numbered 3, 4, 5, 6 and 7, with the longest fibres in group 3. Each group is divided into subgroups or grades identified by the letters A to Z, with 'A' denoting the longest fibre of the group. At LAQ, fibre is further classified by degree of fiberization or "openness", according to the degree the fibres or "pencils" have been separated into smaller bundles. Two or three degrees of openness are available in most grades. Although fibres may be the same length, openness can make a great difference in both product processing and physical properties. For example, more open fibres have a greater surface area.

At LAQ, the grades marketed are shown in Table 1.

TABLE 1 - LAQ Fibre Grades

A STANDARD DESIGNATION OF GRADE	B GUARANTEED MINIMUM TEST				C CURRENT LAQ CLASSIFICATION		
3F	10.5	-3.9	-1.3	-0.3	---	3F4	---
3K	7	-7	-1½	-½	3K3	3K4	---
3R	4	-7	-4	-1	3R3	3R4	---
3T	2	-8	-4	-2	3T3	3T4	---
3Z	1	-9	-4	-2	3Z3	3Z4	---
4A	0	-8	-6	-2	4A3	4A4	---
4D	0	-7	-6	-3	4D2	4D4	---
4K	0	-4	-9	-3	4K3	4K4	---
4M	0	-4	-8	-3	---	4M4	---
4T	0	-2	-10	-4	4T3	4T4	4T5
5D	0	-½	-10½	-5	5D3	5D4	5D5
5K	0	-0	-12	-4	5K3	5K4	---
5M	0	-0	-11	-5	5M3	5M4	---
5R	0	-0	-10	-6	5R3	5R4	---
5Z	0	-0	-8.6	-7.4	---	---	---
6D	0	-0	-7	-9	6D3	6D4	6D5
7D	0	-0	-5	-11	7D3	7D4	7D5
7F	0	-0	-4	-12	---	7F4	---
7H	0	-0	-3	-13	7H2	7H3	7H4
7K	0	-0	-2	-14	---	7K4	---
7M	0	-0	-1	-15	7M2	7M4	7M5
7R	0	-0	-0	-16	7R2	7R4	7R5
7T	0	-0	-0	-16	7T2	7T4	7T5

COLUMN A	indicates standard groups and grades.
COLUMN B	indicates minimum number of ounces retained on four Quebec standard screens for each grade.
COLUMN C	lists specific grades available from LAQ and degree to which fibre has been processed or opened. The third digit indicates openness. Example: 4T3 least open, 4T4 medium open, 4T5 most open.

An approximate breakdown of production at LAQ by grade is:

Grade 3 - 2%
" 4 - 50%
" 5 - 15-20%
" 6 - 15%
" 7 - 18%

The products are compressed into cakes and packaged in 3-ply paper or woven polyethylene bags. The standard unit has been pressure reduced from $0.3m^3$ of bulk material to $0.06m^3$, weighing 50 kilos.

The pressure packed fibre is shipped on pallets or cardboard slipsheets in one or two tonne lots. If requested, the lots can be stretch-wrapped in plastic, which stabilizes the load and prevents damage to the bags in transit.

Shipments in North America are made by rail and truck. A rail freight carload is betweem 45 to 55 tonnes. Shipments sent overseas are transported in standard containers from St. Lawrence River or from Atlantic Coast ports.

3. PROCESS DESCRIPTION

3.1 Process Flow

A review of the LAQ asbestos operations is illustrated in Figure I, Rock Processing and Figure II, Fibre Grading.

The rock processing phase is made up of three circuits; Crushing, Drying and Milling. Comminution is confined to the crushing and drying circuits. It is indirectly associated with the mill rock line and fibre grading.

Asbestos manufacturing is different from other industrial minerals because only a small percentage (18%) of the rock mined is actually milled and the comminution process "releases" the mineral from the host rock.

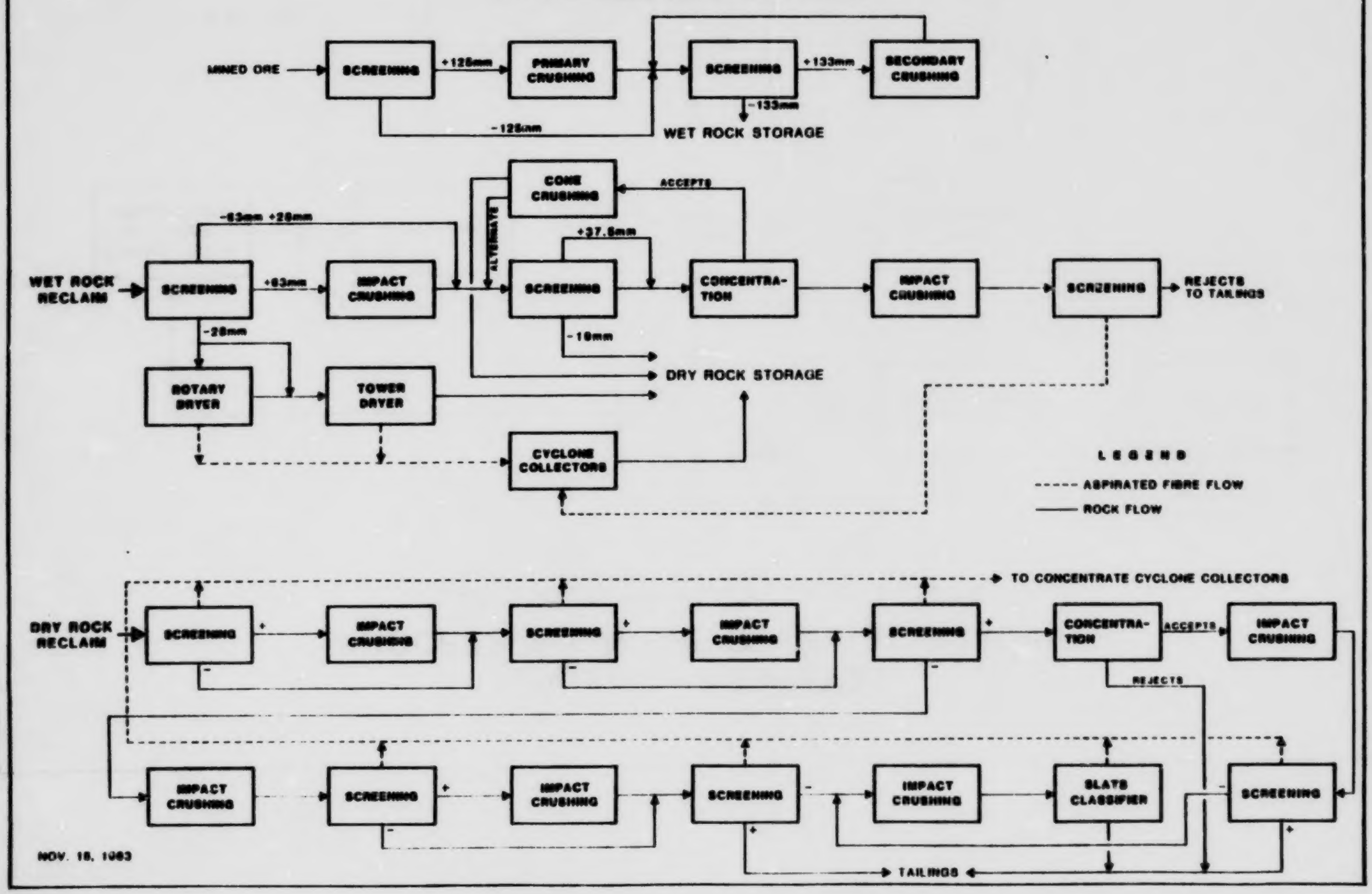
3.2 Crushing

After mining, the primary rock processing operation is crushing, which is detailed in Figure III. The equipment is listed in Table 2.

Ore is transported to the primary crusher in 45 or 91 tonne truckloads. It is discharged onto an apron feeder and flows down across the 125 mm operator controlled grizzly to the primary crusher.

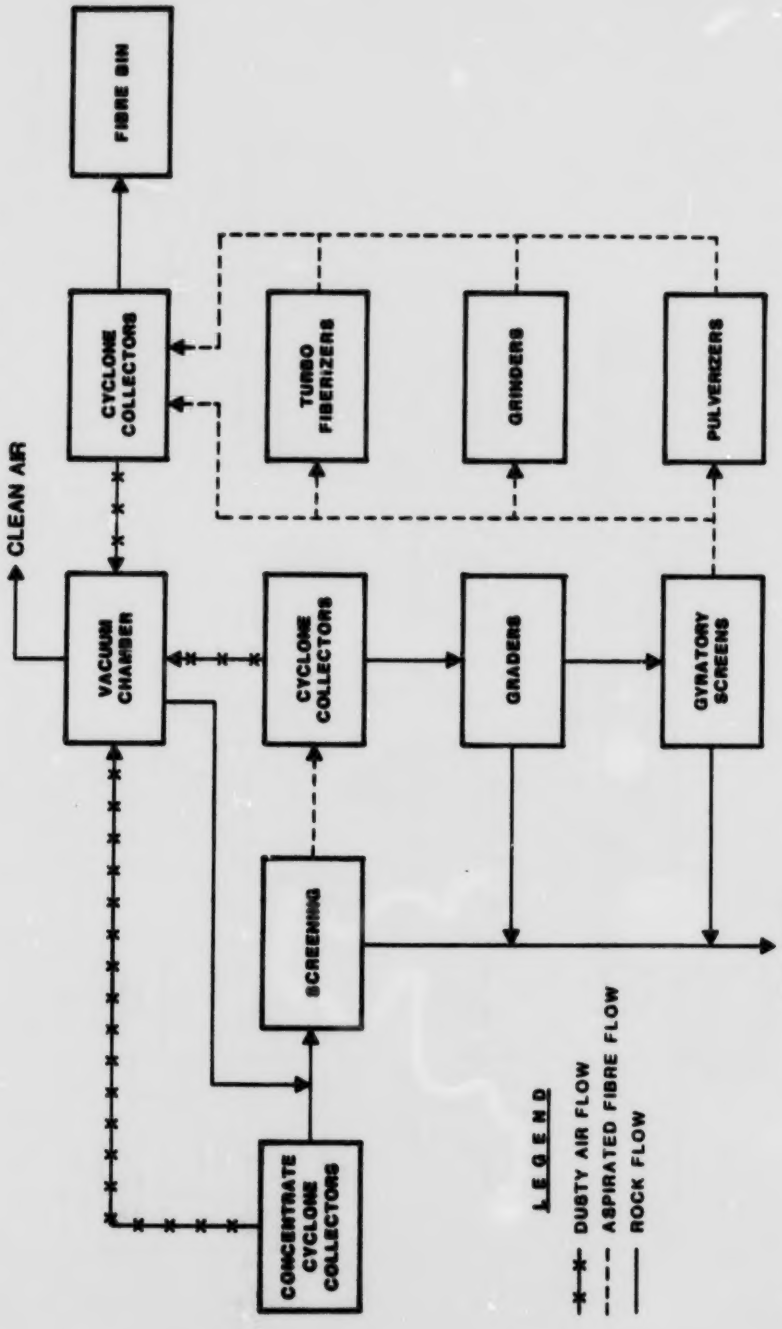
The grizzly undersize (-125 mm) material by-passes the primary crusher and feeds two 133 mm Ty-Rock F800 screens which operate in parallel.

Figure I – ASBESTOS
PROCESS FLOW SHEET – ROCK PROCESSING
LAC D'AMIANTE, BLACK LAKE, QUEBEC

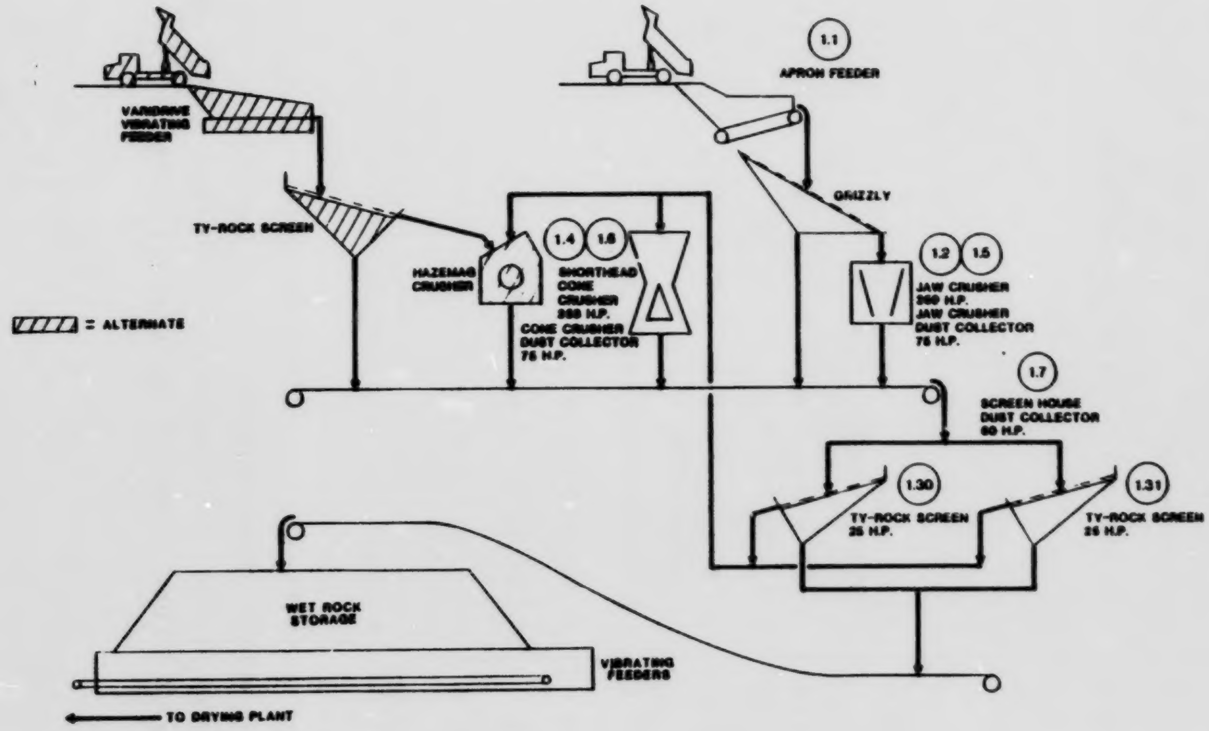

MINED ORE
SCREENING
+125mm
PRIMARY CRUSHING
-125mm
SCREENING
+133mm
SECONDARY CRUSHING
-133mm
WET ROCK STORAGE
WET ROCK RECLAIM
SCREENING
-63mm +28mm
+63mm
IMPACT CRUSHING
-28mm
CONE CRUSHING
ALTERNATE
ACCEPTS
SCREENING
+37.5mm
-19mm
CONCENTRATION
IMPACT CRUSHING
SCREENING
REJECTS TO TAILINGS
ROTARY DRYER
TOWER DRYER
DRY ROCK STORAGE
CYCLONE COLLECTORS
LEGEND
ASPIRATED FIBRE FLOW
ROCK FLOW
TO CONCENTRATE CYCLONE COLLECTORS
DRY ROCK RECLAIM
SCREENING
+
-
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SCREENING
CONCENTRATION
ACCEPTS
IMPACT CRUSHING
REJECTS
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SCREENING
IMPACT CRUSHING
SLATE CLASSIFIER
SCREENING
TAILINGS

NOV. 18, 1983

Figure II – ASBESTOS
PROCESS FLOW SHEET – FIBRE GRADING
LAC D'AMIANTE, BLACK LAKE, QUEBEC


CLEAN AIR
FIBRE BIN
CYCLONE COLLECTORS
TURBO FIBERIZERS
GRINDERS
PULVERIZERS
VACUUM CHAMBER
CYCLONE COLLECTORS
GRADERS
GYRATORY SCREENS
SCREENING
TAILINGS
CONCENTRATE CYCLONE COLLECTORS
LEGEND
DUSTY AIR FLOW
ASPIRATED FIBRE FLOW
ROCK FLOW

NOV. 15, 1983



VARIDRIVE VIBRATING FEEDER
TY-ROCK SCREEN
= ALTERNATE
HAZEMAG CRUSHER
1.4
1.6
SHORTHEAD CONE CRUSHER 300 H.P.
CONE CRUSHER DUST COLLECTOR 75 H.P.
1.1
APRON FEEDER
GRIZZLY
1.2
1.5
JAW CRUSHER 250 H.P.
JAW CRUSHER DUST COLLECTOR 75 H.P.
1.7
SCREEN HOUSE DUST COLLECTOR 60 H.P.
1.30
TY-ROCK SCREEN 25 H.P.
1.31
TY-ROCK SCREEN 25 H.P.
WET ROCK STORAGE
VIBRATING FEEDERS
TO DRYING PLANT

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 15/11/83
CHECKED DCS
DATE 20/09/84

FIGURE III
CRUSHING CIRCUIT
FLOW DIAGRAM

PLANT N° LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010

TABLE 2 - Crushing Circuit Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Apron Feeder	25/16.7	23.8/16.8
1.2	Jaw Crusher - Traylor (4160V)	250	33
1.3	Ty-Rock Screen - F800	25	25
1.31	Ty-Rock Screen - F800	25	25
1.4	Symons 7ft Cone Crusher (4160V)	250	33
1.5	Jaw Crusher Dust Collector (19,950 CFM)	75	71-75
1.6	Cone Crusher Dust Collector (19,950 CFM)	75	71-75
1.7	Screen House Dust Collector (19,950 CFM)	60	60
2.1	Varidrive Vibrating Feeder	40/27	37/29
2.2	Ty-Rock Screen - F900	45	25
2.3	Hazemag Crusher - N500 (4160V)	450	60
2.4	Hazemag Crusher Dust Collector (22,800 CFM)	100	96

* All motors 550 volt unless noted.

The screens (1.3, 1.31) operate in closed circuit with the secondary cone crusher (1.4) processing the oversize and rescreening the crusher discharge. The undersize (-133 mm) is then conveyed to the wet rock storage area.

The wet rock storage area has a capacity of 136,000 tonnes and is advantageous because:

- it will supply ore to the mill if a serious breakdown in the crushing or screening circuit occurs,
- it facilitates blending of the ore coming from different parts of the ore body,
- it ensures a constant feed to the dryers, eliminating any variation of ore from the mine.

Also, there is an alternate primary system consisting of a variable drive vibrating feeder, a F900 Ty-Rock screen (2.2) and a N500 Hazemag crusher (2.3). Individually, the Hazemag crusher may be used as an alternate secondary crusher or to assist the cone crusher should the feed rate be excessive.

3.3 Drying

Drying is detailed in Figure IV. The associated equipment is listed in Table 3.

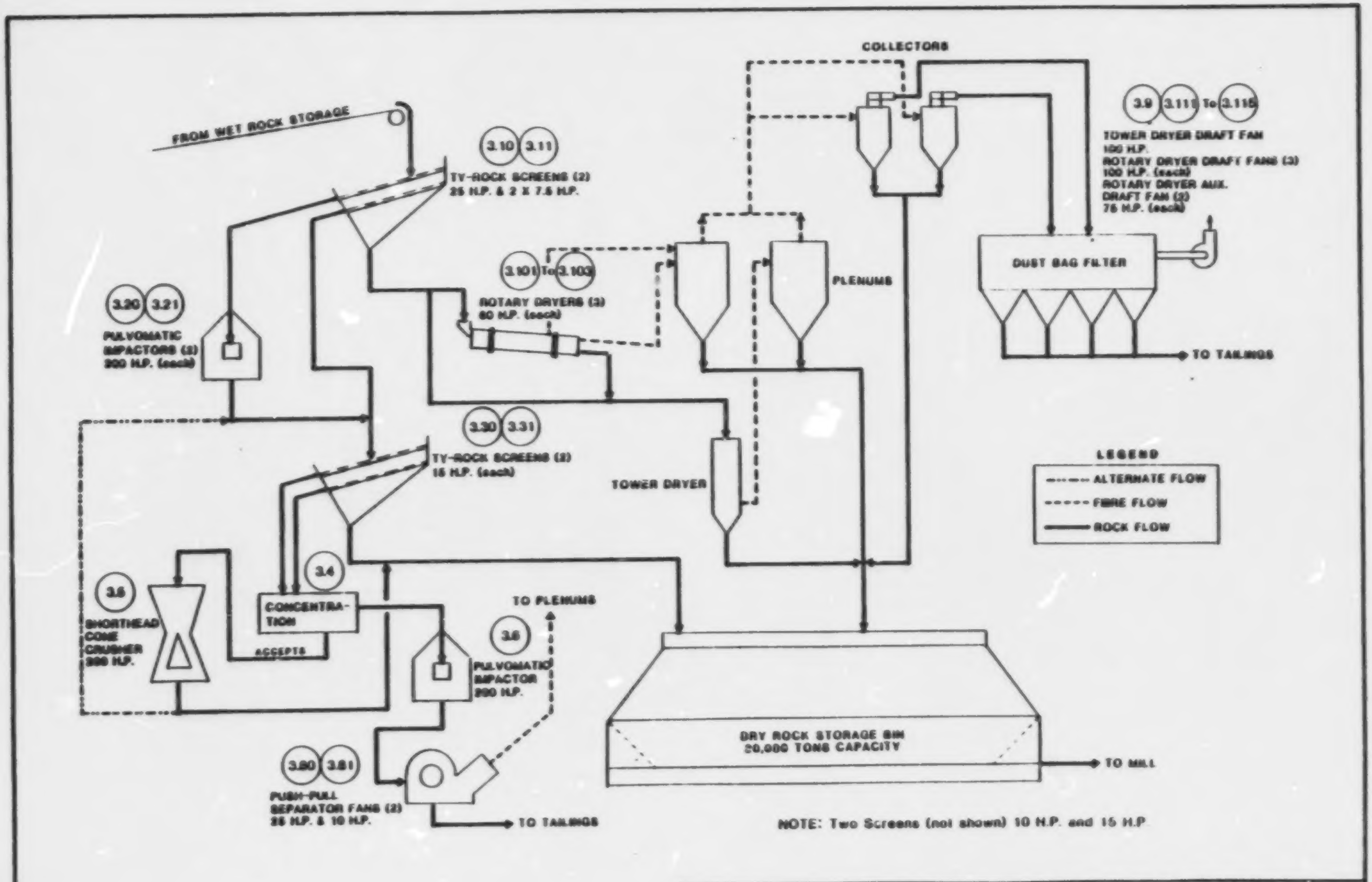
Efficient fibre separation requires that the ore be dry. Depending upon the season and weather conditions, the feed will have a moisture content of between 4 and 10 percent, which must be reduced to between 1.2 and 0.8 percent. Nominally, the feed rate is 700 tonnes per hour.

Vibrating feeders retrieve the rock and discharge it on to a belt conveyor that transports it to two F600 Ty-Rock double-deck vibrating screens (3.1, 3.11).

From screening, the undersize (-28 mm) is fed to the rotary or tower dryers (3.101, 3.103) and on to dry rock storage. The dust and asbestos fibers are removed by the aspiration air flow to the plenum and cyclone collectors, processed and directed to dry rock storage.

The middle cut and oversize, by-pass the dryers. The middle cut flows directly to a second set of Ty-Rock screens (3.3, 3.31) joining the oversize which must first be crushed in the impact crushers (3.2, 3.21).

After screening, the undersize (-19 mm) passes directly to dry rock storage. The middle cut and oversize (+37.5 mm) are sent to concentration (3.4). The accepts proceed to the cone crusher (3.5) and on to dry rock storage. The rejects are directed to a Pulvomatic impactor (3.6), and on to screens (3.7, 3.71) and air separation (3.8, 3.81), with the non-aspirated material going to tailings.


FROM WET ROCK STORAGE
3.10 3.11
TY-ROCK SCREENS (2)
25 H.P. & 2 X 7.5 H.P.
3.20 3.21
PULVOMATIC IMPACTORS (2)
200 H.P. (each)
3.101 To 3.103
ROTARY DRYERS (3)
60 H.P. (each)
COLLECTORS
PLENUMS
3.9 3.111 To 3.115
TOWER DRYER DRAFT FAN
100 H.P.
ROTARY DRYER DRAFT FANS (3)
100 H.P. (each)
ROTARY DRYER AUX.
DRAFT FAN (3)
75 H.P. (each)
DUST BAG FILTER
TO TAILINGS
3.30 3.31
TY-ROCK SCREENS (2)
15 H.P. (each)
TOWER DRYER
LEGEND
ALTERNATE FLOW
FIBRE FLOW
ROCK FLOW
3.5
SHORTHEAD CONE CRUSHER
300 H.P.
3.4
CONCENTRATION
ACCEPTS
TO PLENUMS
3.6
PULVOMATIC IMPACTOR
200 H.P.
3.80 3.81
PUSH-PULL SEPARATOR FANS (2)
25 H.P. & 10 H.P.
TO TAILINGS
DRY ROCK STORAGE BIN
20,000 TONS CAPACITY
TO MILL

NOTE: Two Screens (not shown) 10 H.P. and 15 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 15/11/83
CHECKED DCS
DATE 20/09/84

FIGURE IV
DRYING CIRCUIT
FLOW DIAGRAM

PLANT AT LAC D'AMIANTE
BLACK LAKE, QUEBEC

PROJECT No. 20010

TABLE 3 - Drying Circuit Equipment List

EQUIPMENT		MOTOR*	
NO.	TYPE/MAKE/MODEL	HP	AMPS
3.1	Ty-Rock Screen - F600	25	26
3.11	Ty-Rock Screen - F600	2 x 7.5	7.6
3.2	Pulvomatic Impactor	200	198
3.21	Pulvomatic Impactor	200	198
3.3	Ty-Rock - F600	15	15
3.31	Ty-Rock - F600	15	15
3.4	Concentration	-	-
	Sterns Drum Drive	-	-
	Sterns Drum Magnet	-	-
	Sterns Drum Drive	-	-
	Sterns Drum Magnet	-	-
3.5	5.5' Short Head Cone Crusher (4160V)	200	29
3.6	Pulvomatic Impactor - 42"	200	198
3.7	Screen	10	11
3.71	Screen	15	15
3.8	Push Pull Separator Fan	25	25
3.81	Push Pull Separator Fan	10	10
3.9	Tower Dryer Draft Fan	100	96
3.101	Rotary Dryer Drive #2	60	58
3.102	Rotary Dryer Drive #3	60	58
3.103	Rotary Dryer Drive #4	60	58
3.111	Rotary Dryer Draft Fan	100	96
3.112	Rotary Dryer Draft Fan	100	96
3.113	Rotary Dryer Draft Fan	100	96
3.114	Rotary Dryer Auxiliary Draft Fan	75	72
3.115	Rotary Dryer Auxiliary Draft Fan	75	72

* All motors 550 volt unless noted

3.4 Milling Circuit

Detailed in Figure V is the Milling Circuit. The equipment list is shown in Table 4.

The milling circuit flowrate averages about 8,200 tonnes of ore per day, of which, 3% to 6% is fibre. Thus, the fibre production rate is about 500 tonnes per day.

The milling process has the following functions:

- to reject barren rock at the earliest stage possible,
- to recover the maximum amount of fibre without affecting fibre length or degree of openness,
- to remove residual rock particles,
- to separate the fibre to the required degree of openness and remove fine grit and dust trapped in the fibre,
- to grade the fibre to the required standard classified lengths,
- to package the finished product.

Also, the system must have an effective air handling operation to transport and separate the fibre and to control dust.

There is no standard method of milling asbestos. Each technique is designed to suit the ore from a particular deposit, while maintaining flexibility. However, the basic operations of crushing, drying, fibre separation, cleaning, fiberizing, grading and packaging are common to all mills.

The asbestos fibre is aspirated as it is released everywhere in the circuit. This protects the openness of the fibre and minimizes the absorption of fine dust.

The dry rock storage feed is discharged into a distribution bin which feeds a battery of double-deck vibrating screens (4.1, 4.11, 4.12). The oversize feeds two Torrey Impactors (4.2, 4.21) whose discharge comnbines with the screened undersize to feed the next set of screens (4.3, 4.31), where the process is repeated to feed screens (4.5, 4.51).

At this point, the process divides. The oversize from the top deck of the tandem screens (4.5, 4.51) proceeds to concentration to remove the iron bearing rock. The accepts continue on to a JM fiberizer (4.110) whose discharge forms the feed to screen (4.12).

The oversize from the second deck of the tandem screens (4.5, 4.51) feeds a Denovan Impactor (4.6) and the discharge combines with the screen undersize to feed screens (4.7, 4.71).

The oversize of (4.7, 4.71) is fiberized in a JM fiberizer (4.8) whose discharge and the screens undersize form the feed for screens (4.9, 4.91).

Some consolidation now takes place, with the oversize of screens (4.9, 4.91 and 4.120) being discharged to tailings and the undersize combining to feed a Denovan Impactor (4.130).

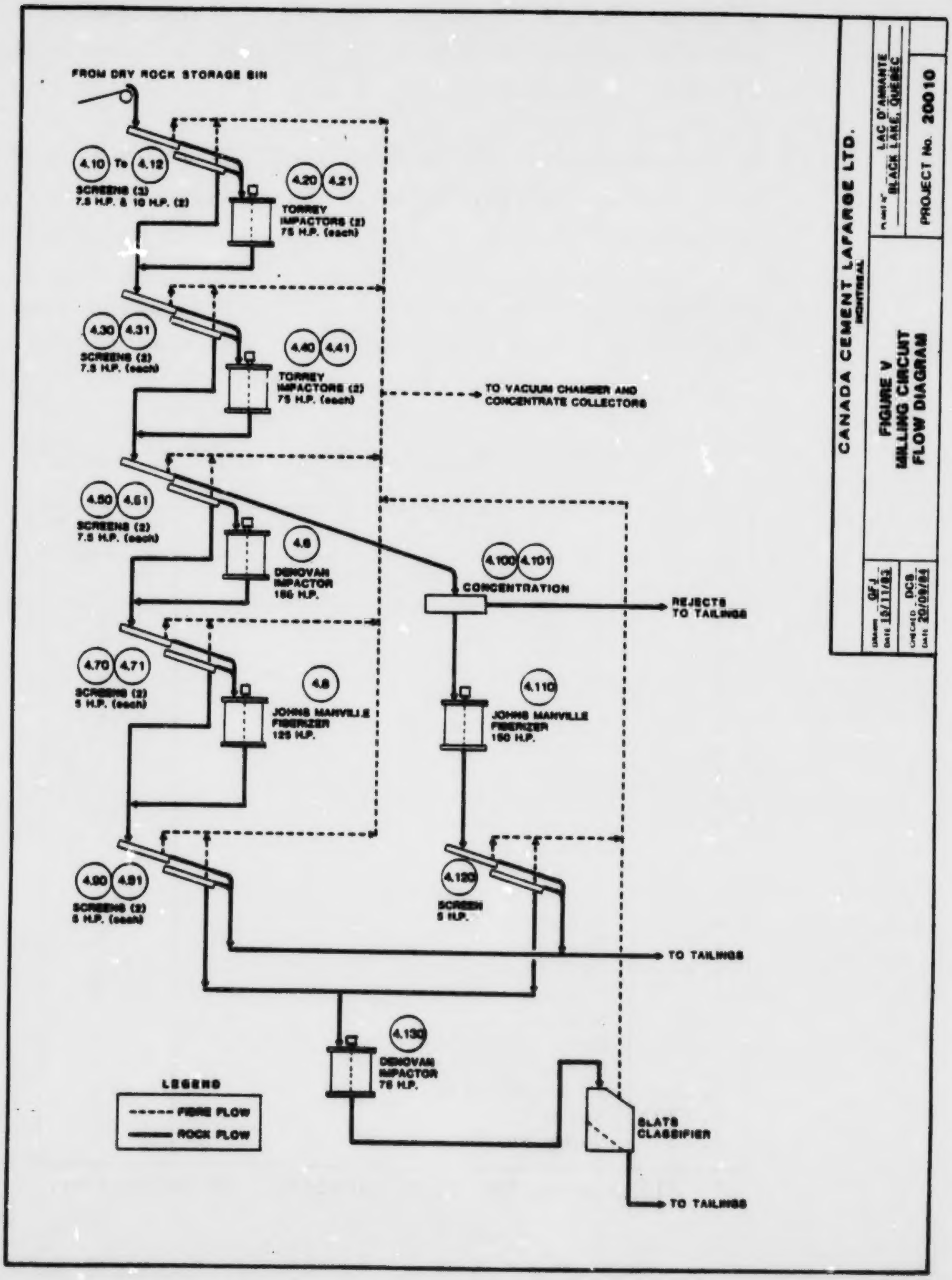
The discharge of the Denovan Impactor (4.130) is conveyed to a slats classifier, where the remaining fibre product is drawn off and the refuse discharged to tailings.

As shown, at each screening or classification step, fibre product is removed by the draft air flow to the concentrate collectors and vacuum chamber.

TABLE 4 - Mill Rock Line Equipment List 3

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
4.1	Screen	7.5	7.6
4.11	Screen	10	11
4.12	Screen	10	11
4.2	Torrey Impactor	75	70
4.21	Torrey Impactor	75	76
4.3	Screen	7.5	7.6
4.31	Screen	7.5	7.6
4.4	Torrey Impactor	75	72
4.41	Torrey Impactor	75	72
4.5	Screen	7.5	7.8
4.51	Screen	7.5	7.8
4.6	Denovan Impactor	150	138
4.7	Screen	5	5.1
4.71	Screen	5	5.1
4.8	JM Fiberizer	125	119
4.9	Screen	5	5.1
4.91	Screen	5	5.1
4.100	Concentration	-	-
4.101	Concentration	-	-
4.110	JM Fiberizer	150	136
4.120	Screen	5	5.1
4.130	Denovan Impactor	75	72

* All motors 550 Volt capacity, unless noted.


FROM DRY ROCK STORAGE BIN
4.10 To 4.12
SCREENS (3)
7.5 H.P. & 10 H.P. (2)
4.20 4.21
TORREY IMPACTORS (2)
75 H.P. (each)
4.30 4.31
SCREENS (2)
7.5 H.P. (each)
4.40 4.41
TORREY IMPACTORS (2)
75 H.P. (each)
TO VACUUM CHAMBER AND CONCENTRATE COLLECTORS
4.50 4.51
SCREENS (2)
7.5 H.P. (each)
4.6
DENOVAN IMPACTOR
186 H.P.
4.100 4.101
CONCENTRATION
REJECTS TO TAILINGS
4.70 4.71
SCREENS (2)
5 H.P. (each)
4.8
JOHNS MANVILLE FIBERIZER
125 H.P.
4.110
JOHNS MANVILLE FIBERIZER
150 H.P.
4.90 4.91
SCREENS (2)
5 H.P. (each)
4.120
SCREEN
5 H.P.
TO TAILINGS
4.130
DENOVAN IMPACTOR
75 H.P.
SLATS CLASSIFIER
TO TAILINGS
LEGEND
----- FIBRE FLOW
—— ROCK FLOW
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE V
MILLING CIRCUIT
FLOW DIAGRAM
PLANT LAC D'AMIANTE
BLACK LAKE, QUEBEC
PROJECT No. 20010
DRAWN GFJ
DATE 15/11/83
CHECKED DCS
DATE 20/09/84

3.5 Fibre Grading

Fibre grading, or the product line process, is detailed in Figure VI and the equipment is listed in Table 5.

Various concentrations of fibre are fed to tandem shaking screens (5.2) for further refinement. The aspirated fibre is segregated and concentrated again in cyclone collectors. The residual material goes to tailings.

The collectors feed a dust grader (5.3), further refining the product, and the discharge feeds gyratory screens (5.4, 5.41), for the final refining step. Next, the fibre is prepared to specification through the use of specialized equipment such as Turbo fiberizers (5.5, 5.51), a grinder (5.6), or a Hurricane pulverizer (5.7).

As shown in Figure VI, screening provides a means of preparing the fibre for aspiration. The "crushing" is used only to release the fibre from the rock, not to reduce the size of the material as in a normal comminution operation.

The fibrous material is vacuumed to the concentrate collectors where the fibres are then discharged to the cleaning, grading and fiberizing circuits. The asbestos dust is filtered out in the vacuum chamber and returned for reprocessing.

3.6 Packaging and Shipping

From the fibre bins, blends are packaged in bags of 3-ply paper or woven polyethylene. The operation is completely automatic, including palletizing. For security and weather protection, one or two tonne shipments can be stretch-wrapped in a strong polyethylene film.

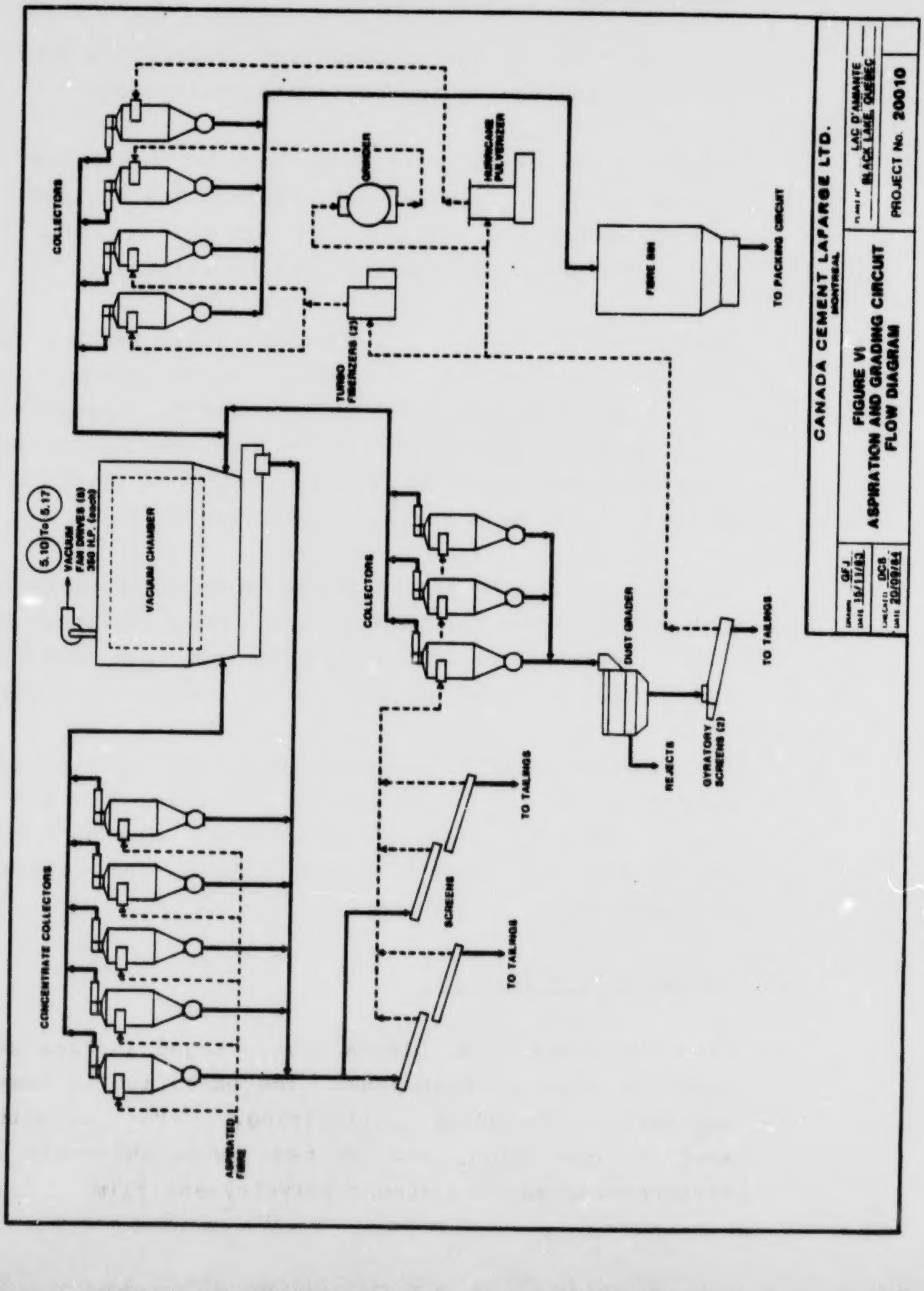

COLLECTORS
GRINDER
HURRICANE PULVERIZER
FIBRE BIN
TO PACKING CIRCUIT
TURBO FIBERIZERS (2)
5.10 To 5.17
VACUUM FAN DRIVES (8) 350 H.P. (each)
VACUUM CHAMBER
COLLECTORS
DUST GRADER
TO TAILINGS
GYRATORY SCREENS (2)
REJECTS
CONCENTRATE COLLECTORS
SCREENS
TO TAILINGS
TO TAILINGS
ASPIRATED FIBRE
CANADA CEMENT LAFARGE LTD.
MONTREAL
PLANT AT LAC D'AMIANTE BLACK LAKE, QUEBEC
PROJECT No. 20010
DRAWN GFJ DATE 19/11/82
CHECKED DCS DATE 20/09/84

FIGURE VI
ASPIRATION AND GRADING CIRCUIT
FLOW DIAGRAM

TABLE 5 - Cleaning, Grading and Fiberizing Circuit Equipment List 4

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	Vacuum Fan Drive #1	350	46
5.11	Vacuum Fan Drive #2	350	46
5.12	Vacuum Fan Drive #3	350	46
5.13	Vacuum Fan Drive #4	350	46
5.14	Vacuum Fan Drive #5	350	46
5.15	Vacuum Fan Drive #6	350	46
5.16	Vacuum Fan Drive #7	350	46
5.17	Vacuum Fan Drive #8	350	47
5.2	Screens		
5.3	Dust Grader	25	26.5
5.4	Gyratory Screen		
5.41	Gyratory Screen		
5.5	Turbo Fiberizer	50	50
5.51	Turbo Fiberizer	40	39
5.6	Grinder	50	46
5.7	Hurricane Pulverizer	125	114

* Vacuum Fan Drives are 4160 Volt capacity, all others are 550 Volts.

3.7 Air Handling System

The production of asbestos requires large quantities of air, which, by the pull-through method, circulates rapidly through the fibre processing and dust control systems. The vacuum chamber, in the milling circuit, passes 336,000 m^3/minute of air through approximately 21,000 polyester filter bags. In addition, each of the other circuits have their own dust collection and vacuum systems.

In the main vacuum chamber, an ambient particulate monitor (APM) is used to measure the amount of respirable dust in the filtered air. The information is used to monitor the quality of air recycled into the mill and to indicate the chamber's operating efficiency.

3.8 Quality Control

To meet rigid consumer specifications, the asbestos industry uses extensive quality control procedures throughout production.

Normally, a small sample from each bag is taken to form a lot and shift composite sample. These are evaluated in accordance with the various Quebec Asbestos Mining Association (QAMA) test methods, to determine the dry and wet screen length distribution, degree of fiberization, grit content, surface area, bulk color, filtration, absorption and asbestos-cement strength.

Table 6 lists the QAMA's standard tests. Detailed procedures are described in the Association's Chrysotile Asbestos Test Manual.

TABLE 6 - QAMA Standard Tests

FIBRE LENGTH TESTS

1. Quebec standard screen
2. Ro-Tap screen
3. Bauer-McNett screen
4. Suter Webb comb
5. Wash test for 200 mesh fines

FIBRE OPENNESS TESTS

1. Wet volume or buoyancy
2. Loose density or dry bulk
3. Surface area by air permeability
4. Crudy or grit content
5. Viscosity
6. Kerosene retention
7. Penetration index
8. Oil absorption

MISCELLANEOUS TESTS

1. Tensile strength
2. Asbestos-cement strength
3. Color
4. Quantitative chemical analysis
5. Moisture content
6. Magnetic rating
7. Freeness or filtration

4. RESULTS AND DISCUSSIONS

The results obtained from the data collected are grouped under the following process headings:

- Crushing
- Drying
- Milling
- Aspiration

4.1 Crushing Circuit

4.11 Electrical Measurements

A summary of the measurements taken from the equipment in this circuit are shown in Table 7.

Electrical demand (kW) was calculated from the measured current (A), voltage (V), and power factor (PF) and applying the values to the formula

$$(kW) = \frac{\sqrt{3}\ VA(PF)}{1000}$$

To measure maximum and minimum amperage, readings were recorded from the local ammeters over a period of several minutes.

Table 7 indicates that both the jaw and the 7' shorthead cone crushers run at full loaded capacity periodically. On the average, they operate at 74% of the total power capacity. Their consumption can, however, fluctuate from 62% to 80% of the circuit's total energy capacity.

The dust collection units use about 25% of the total installed power.

TABLE 7 - Crushing Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW AVG.
No.	EQUIPMENT		
1.1	Apron Feeder	25/16.7	11.1/7.5
1.2	Jaw Crusher	250	153
1.3	Ty-Rock Screen - F800	25	4.9
1.31	Ty-Rock Screen - F800	25	5.0
1.4	7' Shorthead Cone Crusher	250	136
1.5	Jaw Crusher Dust Collector	75	23
1.6	Cone Crusher Dust Collector	75	18
1.7	Screen House Dust Collector	60	43

4.12 Flowrate

The average flow through the primary crushing circuit was 750 tonnes/hour, determined from weightometer information.

4.13 Size Distribution

The quarry feed varies in size distribution from 1m x 1m x 0.3m to fines. The large pieces are relatively soft and fracture easily.

4.14 Specific Power Consumption

From the power measurement calculations and a flowrate of 750 tonnes/hour, the specific power consumption was calculated. The results are shown in Table 8.

TABLE 8 - Crushing - Specific Power Consumption

	kWh/tonne	%
Comminution	0.39	74
Auxiliaries	0.13	26
Total	0.52	100

From the table, the power demand for comminution is minimal.

4.2 Drying Circuit

4.21 Electrical Measurements

The summary of the electrical measurements for the equipment in the circuit are listed in Table 9.

The equipment normally operates under constant load, except for the pulvomatic impactor (3.6). Even here, the fluctuation is minimal.

TABLE 9 - Drying Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
3.1	Ty-Rock Screen - F600	25	8.6
3.11	Ty-Rock Screen - F600	2 x 7.5	2 x 2.6
3.2	Pulvomatic Impactor	200	89
3.21	Pulvomatic Impactor	200	90
3.3	Ty-Rock Screen - F600	15	4.3
3.31	Ty-Rock Screen - F600	15	4.4
3.4	Concentration	-	15.4
3.5	5½' Shorthead Cone Crusher	200	68
3.6	Pulvomatic Impactor	200	103
3.7	Screen	10	3.4
3.71	Screen	15	12.8
3.8	Push-Pull Separator Fan	25	15.6
3.81	Push-Pull Separator Fan	10	5.2
3.9	Tower Dryer Draft Fan	100	72
3.102	Rotary Dryer Drive #3	60	47
3.103	Rotary Dryer Drive #4	60	33
3.112	Rotary Dryer Draft Fan #3	100	49
3.113	Rotary Dryer Draft Fan #4	100	53
3.114	Auxiliary Draft Fan	75	44
3.115	Auxiliary Draft Fan	75	39

4.22 Flowrate

Ore is reclaimed from wet rock storage at 625 tonnes/hour.

Normally, about 20% of the flow is fines (-28mm), which pass directly to the dryers.

The oversize fraction, which represents 50% of the screen feed, is crushed (3.2, 3.21). The middle cut is screened on an intermediate screen, the oversize fraction of which is combined with the crushed product. The combined fractions make up the feed to the secondary screening stage (3.3, 3.31).

The concentration circuit rejects up to 45% of the total feed to tailings, resulting in a "beneficiated" dry ore feed rate of 344 tonnes/hour. This is the rate used to determine the specific cumulative power consumption.

4.23 Size Distribution

Three crushing operations are involved in this circuit: the Pulvomatic impactors (3.2, 3.21), the cone crusher (3.5) and the Pulvomatic impactor for the concentration rejects (3.6).

Samples of the feed and discharge of the cone crusher were taken and a sieve analysis was run at the CCL Testing Laboratory in Belleville, Ontario.

The plant provided size distribution information for the two impactors.

Table 10 consolidates information from all three crushers.

TABLE 10 - Drying Circuit Size Distributions (% Passing)

LAC D'AMIANTE DU QUEBEC, LTEE						
	PULVOMATIC IMPACTOR (3.2)		CONE CRUSHER (3.5)		PULVOMATIC IMPACTOR (3.6)	
mm	FEED	DISCH.	FEED	DISCH.	FEED	DISCH.
133	100				100	100
75		100	100		95.5	99.2
50	47.9	85.0	88.0	100	76.8	88.0
38.1			79.0	94.4		
25.0	9.2	48.9	49.7	68.1	31.3	56.4
19.0	5.2	36.7	26.0	36.7	12.2	40.4
12.5	2.9	24.7	5.7	12.7	1.9	22.3
9.5			5.3	10.2		
6.3		14.0			0.7	10.4
4.75			2.6	6.8		
2.36			2.2	4.8		
1.60						3.9

4.24 Grindability Testing

Due to the fibrous nature of the mineral, grindability testing by the Hardgrove and Bond Index methods proved impossible.

4.25 Specific Energy Consumption

The electrical measurements reported in Table 9 and the beneficiated flowrate (4.22) were required to calculate the energy consumed in the circuit. The results are shown in Table 11.

TABLE 11 - Drying Circuit - Specific Power Consumption

Flowrate: 344 t/h beneficiated dry ore

	kWh/tonne	%
Comminution	1.02	46
Auxiliaries	1.20	54
Total	2.22	100

The comminution equipment includes the Pulvomatic impactors (3.2, 3.21, 3.6) and the 5½' Shorthead cone crusher (3.5).

Worthy of note, is the the air flow equipment's power requirement which is greater than that for comminution.

Comparative power consumption data is given in Table 12.

TABLE 12 - Drying Circuit
Comparative Power Consumption Analysis

	kWh/tonne	%
Comminution	1.02	46
Air Flow	1.04	47
Concentration	.04	2
Screens	.12	5
Total	2.22	100

4.26 Cumulative Power Consumption

A cumulative summary of the power requirements for obtaining dry beneficiated ore are shown in Table 13. The results indicate a fairly even split between comminution and auxiliary power use to this point.

TABLE 13 - Dry Ore Preparation
Cumulative Power Consumption

Flowrate: 344 t/h Beneficiated Dry Ore

	kWh/tonne	%
Comminution	1.72	54
Auxiliaries	1.45	46
Total	3.17	100

4.3 Milling Circuit

4.31 Electrical Measurements

The summary of the electrical measurements for the equipment in the circuit is listed in Table 14.

4.32 Flowrate and Size Distribution

The nominal flowrate is 375 t/h; but during our observation period it was actually 323 t/h for the circuit, or 107.7 t/h for each production line.

No individual sampling was done. However, from information supplied by the plant, size distributions are shown in Table 15.

TABLE 14 - Mill Rock Circuit Measurement

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
4.1	Screen	7.5	1.5
4.11	Screen	10	4.3
4.12	Screen	10	4.7
4.2	Torrey Impactor	75	36
4.21	Torrey Impactor	75	36
4.3	Screen	7.5	4.5
4.31	Screen	7.5	7.0
4.4	Torrey Impactor	75	31
4.41	Torrey Impactor	75	28
4.5	Screen	7.5	4.9
4.51	Screen	7.5	3.9
4.6	Denovan Impactor	150	53
4.7	Screen	5	3.6
4.71	Screen	5	3.5
4.8	J-M Fiberizer	125	41
4.9	Screen	5	4.1
4.91	Screen	5	3.8
4.100	Concentration	-	2.4
4.101	Concentration	-	2.6
4.11	J-M Fiberizer	150	64
4.12	Screen	5	3.7
4.13	Denovan Impactor	75	38

TABLE 15 - Mill Rock Circuit
Size Distributions (% Passing)

mm	TORREY (4.2)		TORREY (4.4)		DENOVAN (4.6)		JM FIBERIZER (4.8)	
	Feed	Disch	Feed	Disch	Feed	Disch	Feed	Disch
5.0	100	100	100					
38.1	99.0	99.8	99.7	100				
25.0	95.0	99.3	98.4	99.8				
19.0	88.0	96.5	95.0	99.3				
16.0	80.5	94.8	90.9	98.4				
12.5	65.4	89.6	81.8	95.1	100			
9.5	44.7	79.9	65.7	87.4		100		
6.3	23.8	64.9	47.1	74.9	53.9	73.9	100	100
2.36	6.0	39.5	18.4	43.9	28.8	40.6	57.3	84.7
1.40	3.3	25.0	6.2	24.6	11.4	18.9	13.2	57.6
1.00	2.7	17.9	3.8	17.1			7.4	39.8
0.600	2.4	13.5	2.2	12.4	4.6	7.3	3.7	28.7
0.425	1.4	9.9	1.6	9.1			3.0	21.0

4.33 Specific Power Consumption

The results from Table 14 and the flowrate for a single line of the circuit were the parameters used in determining specific power consumption.

TABLE 16 - Milling Circuit
Specific Power Consumption

Flowrate: 107.7 t/h Dry Ore (one line only)

	kWh/tonne	%
Comminution	3.04	86
Auxiliaries	0.50	14
Total	3.54	100

4.4 Fibre Grading

In this circuit, the aspiration vacuum fans are involved. The power consumed by the cleaning, grading and fiberizing equipment was not measured, as it is not directly related to comminution.

4.41 Electrical Measurements

TABLE 17 - Aspiration and Grading Circuit

POWER MEASUREMENT CALCULATIONS		MOTOR H.P.	kW
No.	EQUIPMENT		AVG.
5.1	Vacuum Fan Drive #1	350	217
5.11	Vacuum Fan Drive #2	350	223
5.12	Vacuum Fan Drive #3	350	239
5.13	Vacuum Fan Drive #4	350	226
5.14	Vacuum Fan Drive #5	350	219
5.15	Vacuum Fan Drive #6	350	226
5.16	Vacuum Fan Drive #7	350	209
5.17	Vacuum Fan Drive #8	350	247

4.42 Specific Power Consumption

The power consumption is high compared to other circuits in the mill.

The specific power consumption was calculated for the complete milling circuit based on a fibre production rate of 17.85 tonnes per hour. The results are shown in Table 18.

TABLE 18 - Aspiration
Specific Power Consumption

Flowrate: 17.85 t/h of Fibre (Total Mill)

	kWh/tonne
VACUUM CHAMBER	101.2

TABLE 19 - Fibre Production
Average Cumulative Power Consumption

(Based on 5.53% fiber content in the dry ore)

MILL CIRCUIT	TOTAL CONSUMPTION	AUXILIARIES		COMMINUTION	
	kWh/ tonne	kWh/ tonne	% Total Consumption	kWh/ tonne	% Total Consumption
Crushing	17.2	4.5	2	12.7	6
Drying	40.1	21.7	10	18.4	8
Milling	64.1	9.1	4	55.0	25
Aspiration	101.2	101.2	45	-	-
TOTAL	222.6	136.5	61	86.1	39

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study, it can be concluded that:

- the results are considered as a fair representation of the power consumption for comminution by the industry;
- the air handling system is a significant energy consumer;
- the fibre to dry rock ratio of 5.53 percent requires the mining of large quantities of ore to achieve required production rates;
- many comminution stages are required to continuously release the fibre from the host rock.

5.2 Recommendations

Due to the stringent dust control requirements and the present high energy consumption of the air handling system, the use of wet grinding should be investigated.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Asbestos is the generic term used for a number of fibrous mineral silicates found in nature. The six naturally occuring varieties are: chrysotile, amosite, crocidolite, anthophyllite, tremolite and actinolite. The most important variety, chrysotile, which accounts for 93% of the world production, is the only one mined in Canada. It is a fibrous form of serpentine which can be either white, gray, green or yellowish. Crocidolite and amosite are used in industrial applications in other countries.

The theoretical chemical formulae for the three important types of asbestos are as follows:

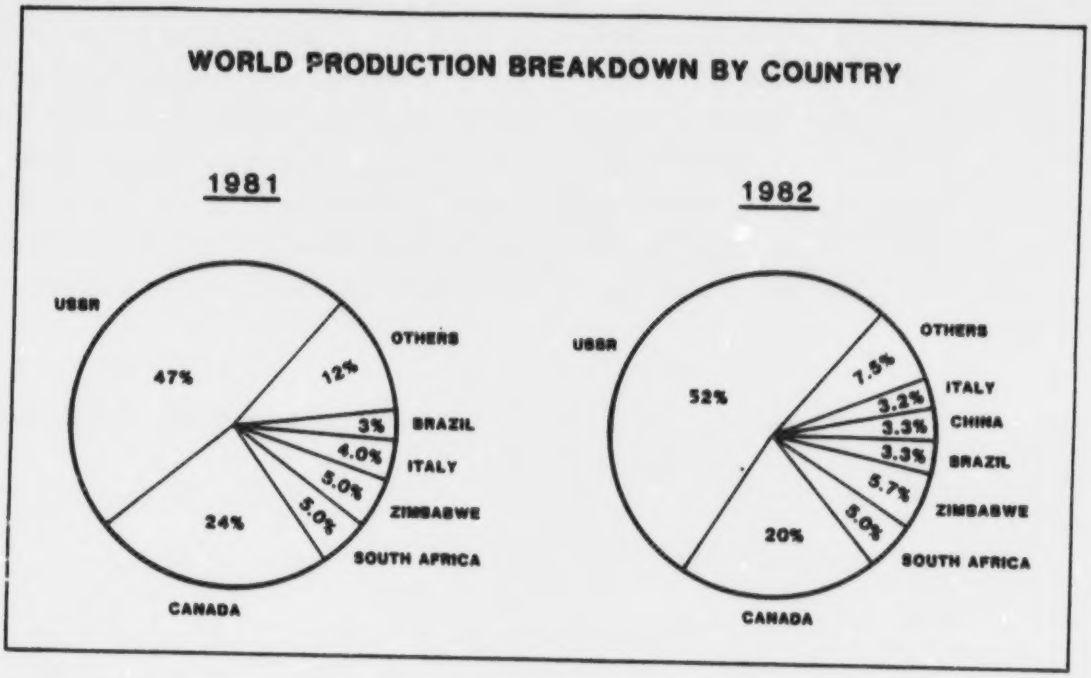
Chrysotile: $3MgO, 2SiO_2, {}_2H_2O$

Crocidolite (blue asbestos): $Na_2O, Fe_2O, {}_3F_eO, {}_8S_iO_2, H_2O$

Amosite: $5.5FeO, 1.5MgO, 8SiO_2, H_2O$

The world production was estimated at about 4,200,000 tonnes in 1982. U.S.S.R. is the world's largest producer, followed by Canada. The breakdown of world production by country for 1981 and 1982 is illustrated in Figure I.

FIGURE I - Breakdown of the World Production by Country (1981 - 1982)[2]



Source: Canadian Mining Journal, February 1983 & 1984.

The ore is milled to recover fibres. The grading of the final product depends mainly on fibre length distribution and degree of openness.

Primary crushing may be done in underground stations or in surface plants by jaw or gyratory crushers. The reduction is normally about 18 cm at this point. It is commonly followed by secondary crushing using either gyratory or cone crushers.

An early concentration stage occurs in these circuits to reject barren rock by selective impact crushing and screening, and by magnetic separation. The ore is dried in rotary or vertical towers to remove the surface moisture without dehydration.

The release and separation of fibre from the host rock is achieved through successive stages of comminution by impact. The released fibre is removed by screening and aspiration. The type of machines used in these stages depends on the required degree of openness.

Each product obtained from primary fibre separation is treated in a separate cleaning circuit and kept separate until final grading. Various grades are derived by using vibrating screens or rotary type graders. The fibre is then sized, cleaned and blended to meet the customers' requirements.

A complex air handling and dust collection system is necessary for collecting and conveying material.

The Canadian Industry

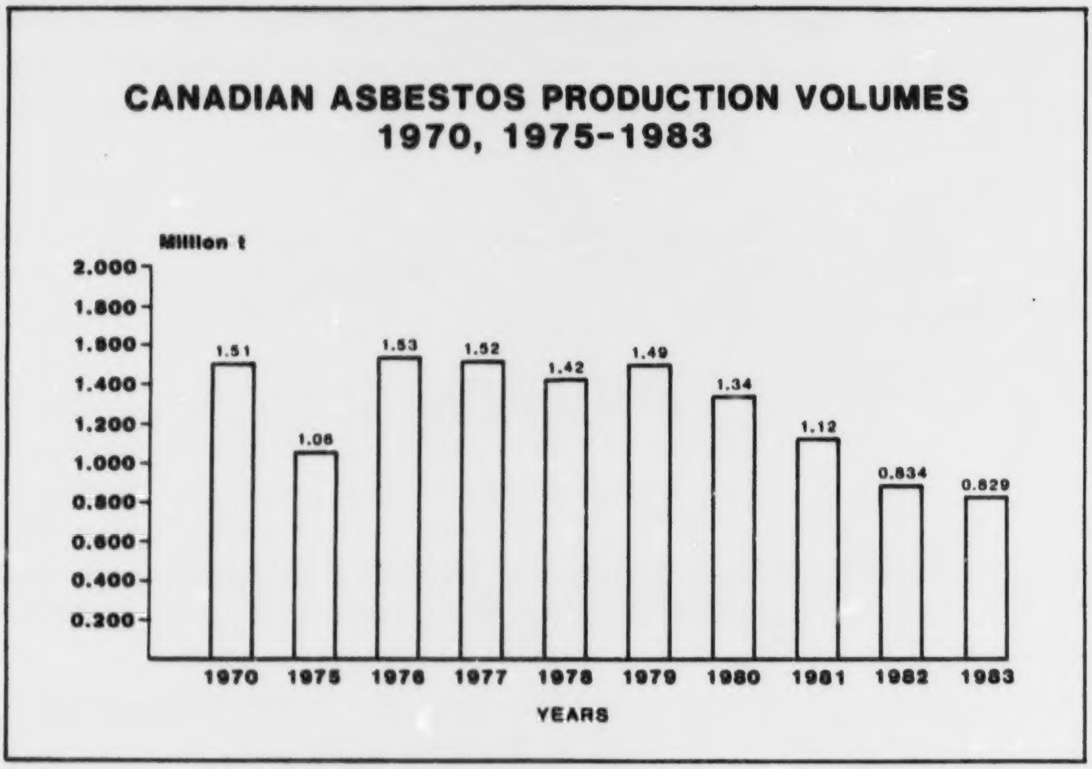
In 1870, asbestos was first mined in Canada in the province of Quebec. Today, Quebec remains the principal producer, representing about 85 to 90 percent of Canada's production. Other operations are in British Columbia and Newfoundland. A breakdown by province for 1982 and 1983 is shown in Table 1.

TABLE 1 - Breakdown of the Asbestos Production by Province (1982-1983)[2]

Province	1982		1983	
	Tonnes	Million $	Tonnes	Million $
Quebec	745 000	298	717 000	315
British Columbia	76 000	57	80 000	70
Newfoundland	13 000	9	32 000	17
Total	834 000	364	829 000	402

Canadian production volumes in 1970 and from 1975 to 1983, can be seen in Figure II.

FIGURE II - Canada, Production Volumes 1970, 1975-83[2]



Source: Canadian Mining Journal, February 1983 & 1984.

Exports generally account for 95% of Canadian production and represent 50% of the world's asbestos exports.

Table 2 lists Canadian producers, mine locations and mill capacities.

TABLE 2 - Canadian Asbestos Producers, 1983[2]

PRODUCERS	MINE LOCATION	MILL CAPACITY (tonnes)		REMARKS
		ore /day	fibre /year	
Baie Verte Mines Inc.	Baie Verte, Nfld.	6 600	80 000	Open pit
Carey Canada Inc.	E. Broughton, Que.	6 800	210 000	Open pit. Mainly produces groups 6 & 7.
Asbestos Corporation Limited				Purchased in 1982 by Société nationale de l'amiante (SNA) (Que. Crown corp.)
Asbestos Hill mine	Putunig, Que.	5 400	90 000	Mining ceased indefinitely. Final processing of fibre in W. Germany.
British Canadian mine	Black Lake, Que.	12 000		Open pit, two milling plants
King-Beaver mine	Thetford Mines, Que.	7 000	210 000	Underground & open pit.
Normandie mine	Black Lake, Que.			Reserves exhausted. Mill processes K-B open pit ore.
Bell Asbestos Mines, Ltd.	Thetford Mines, Que.	2 700	55 000	Underground. Purchased in 1980 by SNA (Quebec Crown corp.)
Lake Asbestos of Quebec, Ltd	Black Lake, Que.	9 000	235 000	Open pit.
National Mines Division	Thetford Mines, Que.	4 000		Open pit.
JM Asbestos Inc. Jeffrey mine	Asbestos, Que.	30 000	645 000	Open pit (western world's largest known asb. deposit).
Brinco Mining Limited Cassiar mine	Cassiar, B.C.	5 000	100 000	Open pit.

Chrysotile is the result of the alteration and metamorphosis of basic igneous rocks rich in magnesium silicate. The approximate composition of chrysotile is shown in Table 3.

TABLE 3 - Approximate Composition of Chrysotile[4]

Component	%
SiO_2	37-44
MgO	39-44
FeO	0-6
Fe_2O_3	0.1-5
Al_2O_3	0.2-1.5
H_2O	12-15

Typical impurities in chrysotile are iron, chrome and nickel.

Some physical qualities of interest include large surface area, good resistance to heat and oxydation, and high flexibility. Chrysolite also mixes well with resins and cements and has good spinnability.

Representative physical properties are shown in Table 4.

TABLE 4 - Properties of Chrysotile Fibre[4]

Specific Heat, kJ/kg.K	1.113
Tensile Strength, MPa	551.6 - 689.5
Fusion Point, °C	1521

Asbestos fibre is classified and sold by groups. The longest fibres are the most expensive. Groups 7, 8 and 9 are graded by bulk density measure.

The major uses of asbestos are listed in Table 5.

TABLE 5 - Possible Uses of Chrysotile Asbestos Fibre

Fibre Class	Groups	Uses
LONG	1 and 2 Crudes	Processed industrially into long spinning fibres used in textiles and the electrical industry.
	3 Milled	Textiles, asbestos papers, packings, brake linings, clutch facings, pipe coverings, and insulating blocks.
MEDIUM	4 Milled	Reinforcing in asbestos-cement products: pipe, shingles, jackets pipe coverings, asbestos-cement packing, gaskets, millboards, roof coatings and plastics.
	5 Milled	Asbestos-cement sheets, corrugated or flat boards, pipes, electrical panels, asbestos papers, millboards, pipe coverings, brake linings, asbestos-cements, roof coatings, putties and plastics.
	6 Milled	Asbestos-cement shingles, corrugated or flat sheets, boards, brake linings, asbestos papers, millboards, asphalt roof coatings, putties and plastics.
SHORT	7, 8, 9 Milled	Certain papers, insulating cement, asphalt roof coatings, putties, paints, welding rods, floor tiles, plastics, acoustical plaster, fibrated greases, oil well muds.

Uniformity of product is one of the most important characteristics demanded by the consumer. Fibre quality is controlled during production by tests made on samples obtained by automatic samplers in the milling circuit.[3]

The only test recognized in Canada is the Quebec Asbestos Mining Association (QAMA) classification known as the Quebec Standard Test (QST). It serves as a production control and as the basis for sale of Canadian asbestos.

The QST is a dry screen analysis which gives the fibre length distribution. This test is made in a QST machine consisting of a nest of three sieves with 12.5 mm, 4.75 mm and 1.70 mm openings and a pan. A test is made with a 1 lb fibre sample which is mechanically shaken for 600 revolutions at 328 rpm. The results, in terms of the weight of fibre remaining on each screen and pan, indicate the relative lengths of the fibres, as shown in Table 6.[3,4]

Other tests are made at the request of consumers to meet their specific needs: viscosity, absorption, fines content, grit, bulk density, soluble salts, magnetic content, compressibility, flexibility, flexing, tensile strength, colour, surface area, filterability, strength units and air permeability.[4]

TABLE 6 - Typical QST Results for the Major Fibre Groups

Fibre Class	Group	½ in. oz	4 mesh oz	10 mesh oz	Pan oz	Total oz
Long Spinning Fibre	3	4	7	4	1	16
Medium Asbestos-Cement Fibre	4	0	4	8	4	16
Paper Stock Fibre	5	0	0	12	4	16
Paper and Shingle Fibre	6	0	0	7	9	16
Shorts	7	0	0	0	16	16

Examples of tests required for some specific uses are shown in Table 7.

TABLE 7 - Asbestos Tests for Specific Uses

PRODUCTS	TESTS REQUIRED
Asbestos-Cement Grades	Strength, fibre length and distribution, filtering rate, dust content
Paper Grades	Length distribution, colour, degree of openness
Plastic Industry	Dust content, grit content, iron and magnetite content

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REFERENCES

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CEMENT

134-75
PROCEDE Plandex R PROCESS
MONTREAL, QUEBEC

THE CEMENT INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

DSS File Number: 23SQ.23440-2-9016A
DSS Contract Serial Number: OSQ82-00228

TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 6

   2.1 History and Organization 2
   2.2 Products 5
   2.3 Raw Materials 6

3. PROCESS DESCRIPITON 7 - 17

   3.1 General 7
   3.2 Quarrying and Crushing 7
   3.3 Raw Grinding 10
   3.4 Burning 13
   3.5 Finish Grinding 15

4. RESULTS AND DISCUSSION 18 - 36

4.1 Crushing 18
   4.11 Electrical Measurements 18
   4.12 Flowrates 18
   4.13 Crusher Feed Size Distribution 19
   4.14 Specific Energy Consumption 19

4.2 Raw Grinding 20
   4.21 Electrical Measurements 20
   4.22 Flowrates 21
   4.23 Grindability 21
   4.24 Chemical Analysis 22
   4.25 Particle Size Distribution 22
   4.26 Circulating Load and Separator Performance 24
   4.27 Specific Energy Consumption 26

TABLE OF CONTENTS
(cont'd)

Page No.

4.3 Finish Grinding 27
- 4.31 Electrical Measurements 27
- 4.32 Flowrates 28
- 4.33 Grindability 28
- 4.34 Chemical Analysis 29
- 4.35 Particle Size Distribution 29
- 4.36 Internal Sampling 31
- 4.37 Residence Time Distribution 33
- 4.38 Circulating Load and Separator Performance 34
- 4.39 Specific Energy Consumption 35

5. CONCLUSIONS 37 - 39

APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Canada Cement Lafarge Ltd.

Plant Location:

St. Constant, Quebec

The study follows the format of the others in the series. It introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the visited plant. The measurements made and results obtained are then reported and discussed and conclusions are drawn.

For readers who are not familiar with the cement industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 History and Organization

The history of Canada Cement Lafarge dates back to 1909 and the formation of the Canada Cement Company. It was created by the amalgamation of a number of companies with plants in Quebec at Montreal and Hull, and in Ontario at Belleville and Port Colborne. Shortly afterwards, the company acquired cement manufacturing facilities at Exshaw, Alberta.

The amalgamation was the result of over-expansion of cement capacity in the previous decade, leading to stiff competition among producers with little or no profits or cash flow for operation or improvement of factilities. The newly-formed company acted as a stabilizing force in the Canadian cement industry, providing more even pricing and eliminating much of the over-capacity. The operation was well organized and generated profits so that finances became available for a continuous program of improvement. The head offices of the Canada Cement company were established in Montreal and were moved to the Canada Cement Company Building in downtown Montreal in 1922.

The first completely new facility constructed by the company was a fully integrated manufacturing plant at Fort Whyte near Winnipeg, Manitoba.

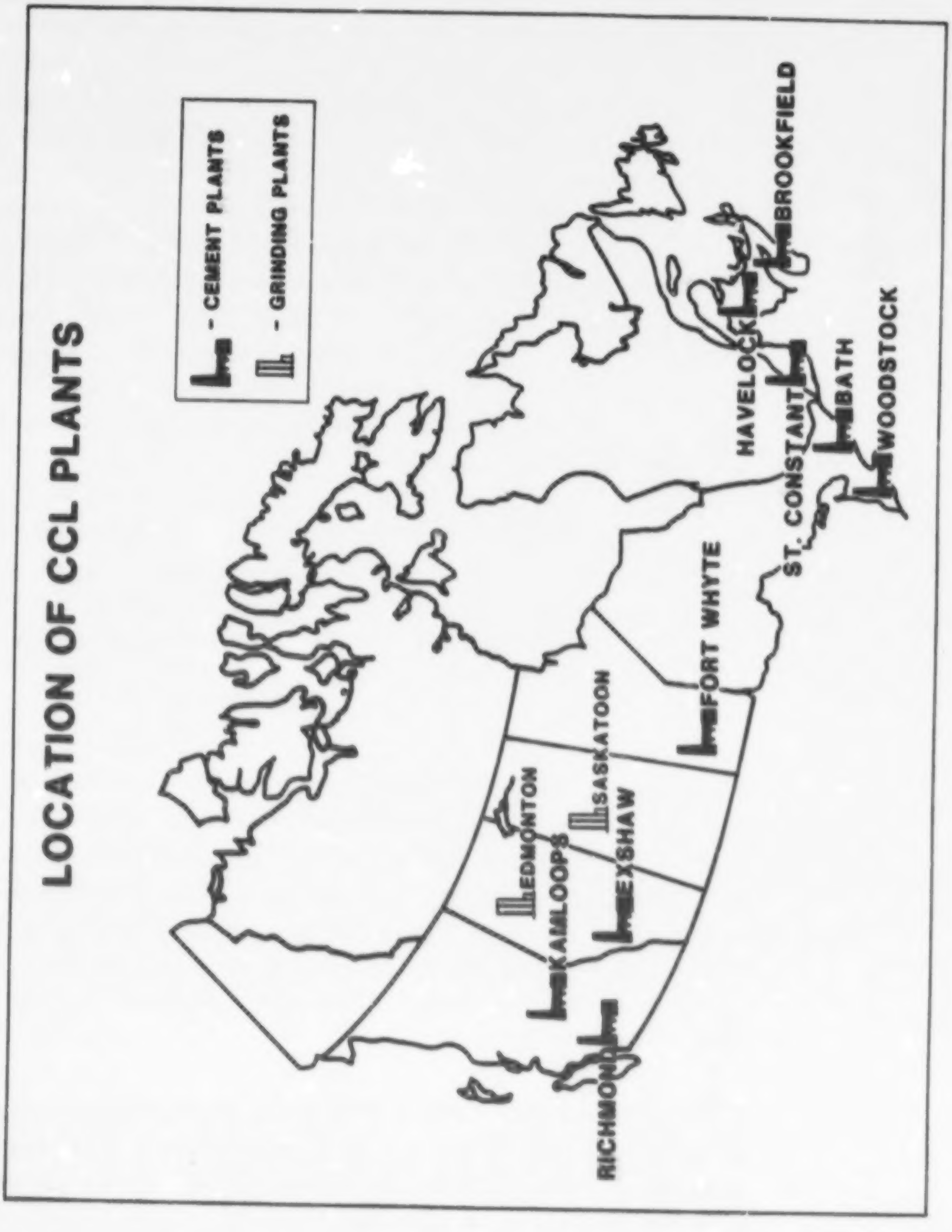
One of the major programs carried out by the company was the conversion of its kilns from the dry to the wet process. This was begun in the late twenties and continued into the thirties. The wet process was preferable because wet raw grinding was cleaner and the raw kiln feed, in the form of a slurry, was easier to handle and blend. Also, in those days, a single large wet kiln could replace several small dry kilns.

The demand for cement fell sharply during the depression and did not recover to pre-depression levels until after the Second World War. When the war ended, many long-deferred construction projects were begun and the cement industry in Canada witnessed several boom years. The Canada Cement Company accelerated its investment program, and began construction of new facilities. A dry-process plant at Havelock, New Brunswick was brought on-stream in 1951 and was the first cement manufacturing facility in the Maritimes. Interest was reviving in the dry-process because of the increased fuel efficiency. Another new plant was started-up in 1956 at Woodstock, Ontario, and in 1965, a second Maritime plant went into operation at Brookfield, Nova Scotia.

Along with its efforts directed towards its cement manufacturing facilities, the company, during the sixties, established the practice of vertical integration, becoming involved in supplying ready-mixed concrete, preformed concrete products and aggregates.

In 1970, the company merged with Lafarge Canada Ltd., forming Canada Cement Lafarge Ltd. Lafarge Canada had been active in Canada since the fifties and had established plants at Richmond and Kamloops, British Columbia, and at St. Constant, Quebec. These operations, combined with those of the Canada Cement Company, gave the new company, Canada Cement Lafarge Ltd., manufacturing and distribution facilities in all regions of the country. (See map on page 4).

Since the merger, Canada Cement Lafarge has continued its program of expansion and modernization of its facilities including construction of a new plant at Bath, Ontario, and two new kilns at Exshaw.



LOCATION OF CCL PLANTS

- CEMENT PLANTS
- GRINDING PLANTS
BROOKFIELD
HAVELOCK
BATH
WOODSTOCK
ST. CONSTANT
FORT WHYTE
SASKATOON
EDMONTON
EXSHAW
KAMLOOPS
RICHMOND

2.2 Products

The company's products, as defined by the CSA, are shown in Table 1 below.

TABLE 1 - CSA Classification of Portland Cements

NAME	TYPE	APPLICATION
Normal	10	For use in concrete construction when the special properties of the other types are not required.
Moderate	20	For use in general concrete construction exposed to moderate sulphate action, or when moderate heat of hydration is required.
High Early	30	For use when high early strength is required.
Low Heat	40	For use when low heat of hydration is required.
Sulphate-Resistant	50	For use when high sulphate-resistance is required.
Oil Well	58-59	For cementing the casing in place in oil wells.
Masonry	60	For using in bonding brick or concrete block.

2.3 Raw Materials

Raw materials for the Portland cement manufacturing process are calcium carbonate, silica, alumina and iron, which are suitably proportioned to give the right balance of oxides after pyroprocessing.

The major constituent is calcium carbonate which is generally obtained from limestone. Other sources are chalks, marls and oyster shells.

Sources of silica are sand, sandstone, clay or shale while alumina is found in shale, clay, fly ash or bauxite. Iron is supplied by iron ore, mill scale or fly ash.

Since cement making is a chemical process, there is considerable flexibility in the choice of raw materials. The available limestone may contain some or all of the other required components in varying degrees. So-called "natural cement" rocks have the required composition for cement making.

3. PROCESS DESCRIPTION

3.1 General

The process at St. Constant, despite having the capacity of producing about 900,000 tonnes of finished product per year, is relatively straightforward from a process flow point of view (Figure I).

The process is broken down into four major functions: quarrying and crushing, raw grinding, burning and finish grinding. At St. Constant the stone is blasted and trucked to the crusher. The crushed stone goes through a stacker-reclaim system which serves both to store and blend the stone. The stone is then mixed with other raw materials, sand and iron, which serve to adjust the chemical composition of the mix prior to grinding in the raw mill. The resulting raw mix is stored and blended in aeration silos and fed to the kilns for pyroprocessing. The resulting clinker is cooled and stored or fed directly to the finish mill where it is ground with a small amount of gypsum.

3.2 Quarrying and Crushing

Blasted rock from the quarry is dumped by quarry truck into a hopper, leading to a vibrating feeder-grizzly (Figure II). The rock is then fed directly to a 700 HP Hazemag rotary crusher and conveyed to two vibrating screens operating in parallel. The +19 mm stone is screened out and returned to the crusher. The product from the screens is transported a distance of 850 meters on a belt conveyor to the storage hall. Table 2 presents the equipment list for the crushing department.

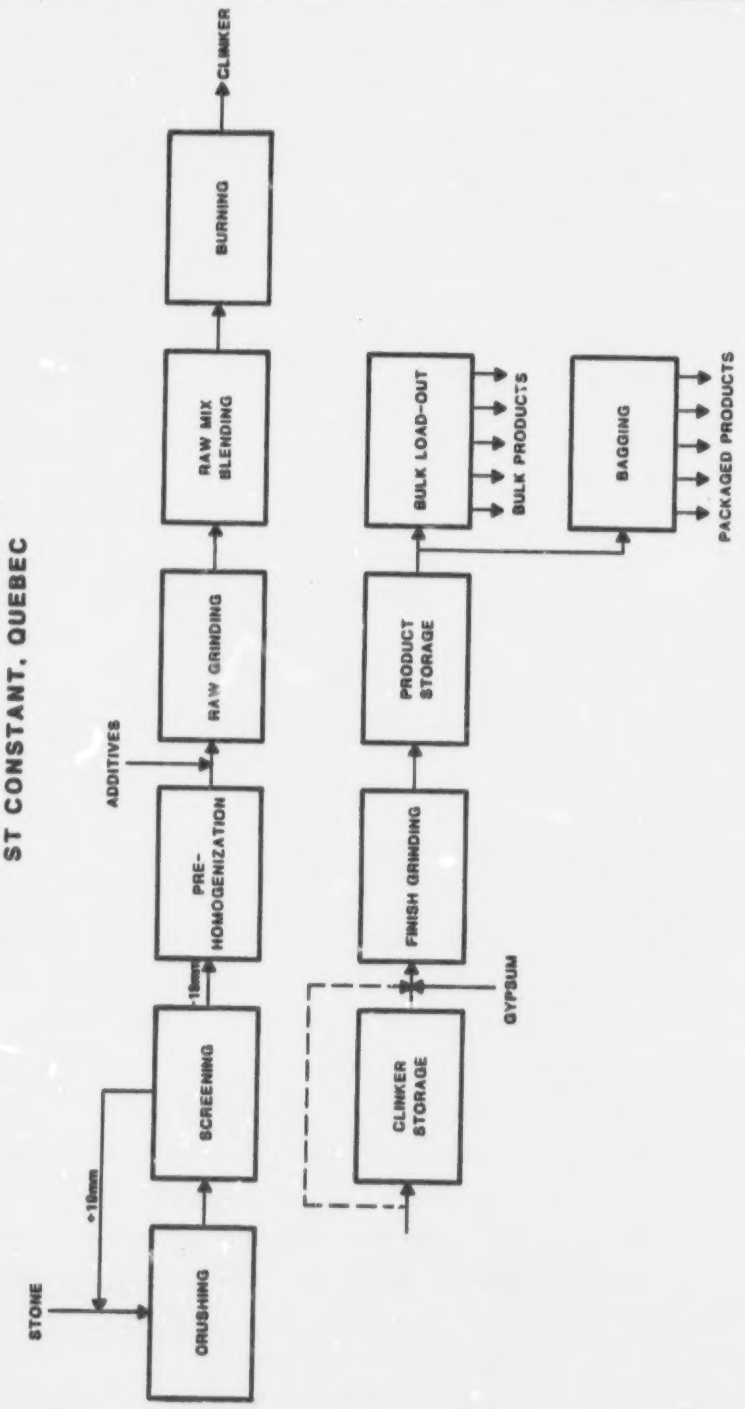
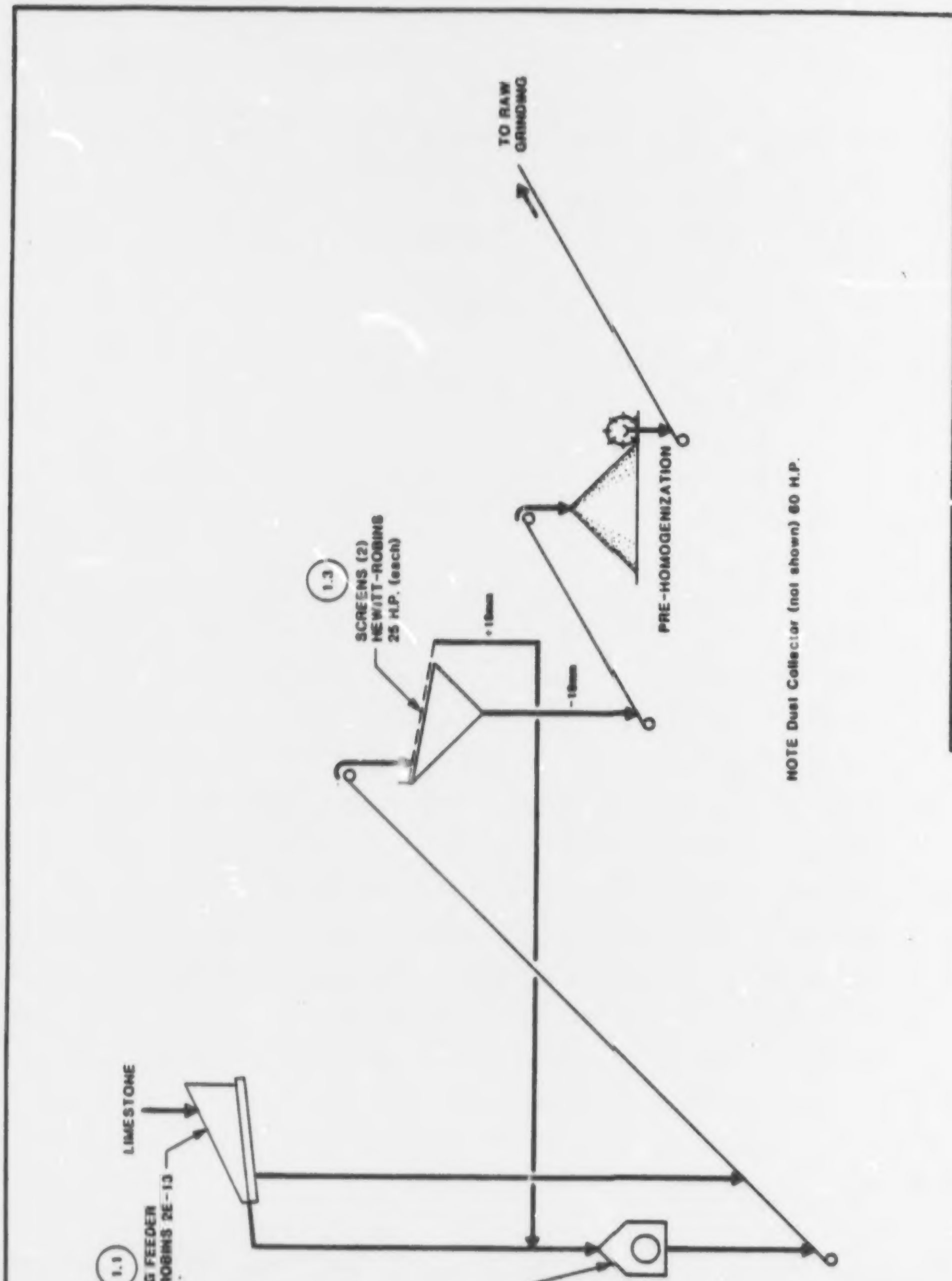

STONE
CRUSHING
+10mm
SCREENING
-10mm
PRE-HOMOGENIZATION
ADDITIVES
RAW GRINDING
RAW MIX BLENDING
BURNING
CLINKER
CLINKER STORAGE
GYPSUM
FINISH GRINDING
PRODUCT STORAGE
BULK LOAD-OUT
BULK PRODUCTS
BAGGING
PACKAGED PRODUCTS

Figure I - PROCESS FLOW SHEET
CANADA CEMENT LAFARGE LTD
ST CONSTANT, QUEBEC


TO RAW GRINDING
1.3
SCREENS (2)
HEWITT-ROBINS
25 H.P. (each)
+18mm
-18mm
PRE-HOMOGENIZATION
NOTE Dust Collector (not shown) 60 H.P.
LIMESTONE
1.1
VIBRATING FEEDER
HEWITT-ROBINS 2E-13
75 H.P.
1.2
CRUSHER
HAZEMAG
TYPE AP-7
700 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE II
CRUSHING CIRCUIT
FLOW DIAGRAM

PLANT CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC

PROJECT No. 20010

DRAWN FGM
DATE 14/12/83
CHECKED DCS
DATE 20/08/84

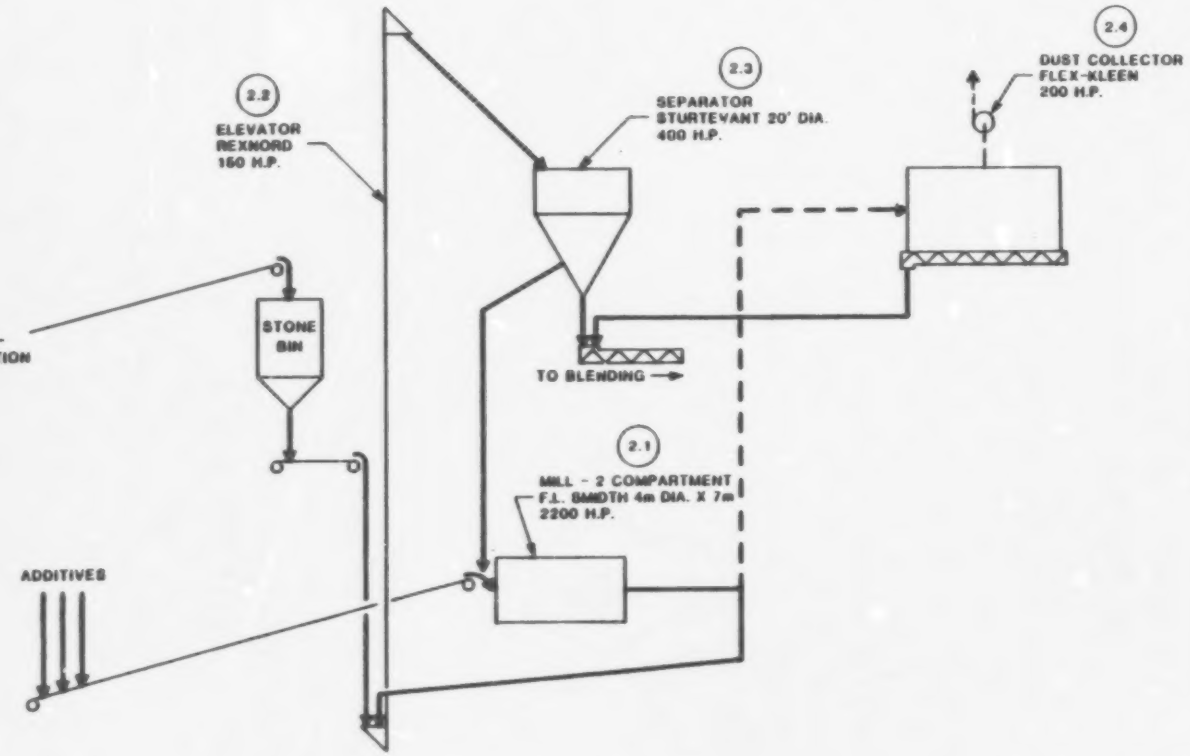
TABLE 2 - Crushing - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
1.1	Vibrating Feeder Hewitt-Robins 2E-13	75	550	75
1.2	Crusher Hazemag Type AP-7	700	4160	86
1.3	Screens (2) Hewitt-Robins	25	550	24
1.4	Dust Collector Norblo 6 Compartment	60	550	57

At the storage hall the stone is processed through a stacking-reclaiming system which serves to even out chemical variation in the stone as quarried. With this system, a pile is built by spreading the stone over the entire width of the pile giving layers of different stone. Once the pile is complete, the material is reclaimed with a bucket wheel and discharged to a belt conveyor. In contrast to the way the pile is built, it is reclaimed by taking cuts across the pile, traversing the layers. Thus, by mixing stone crushed at various times, the variation is reduced. In practice, 2 piles are used, one being reclaimed as a new one is built. This process is referred to as pre-homogenization.

3.3 Raw Grinding

The stone is reclaimed to a bin for feeding to the raw mill (Fig. III). It is necessary for the stone to be dried before further processing. Thus, instead of being fed directly to the mill, the stone is fed into the mill


2.2
ELEVATOR
REXNORD
150 H.P.
2.3
SEPARATOR
STURTEVANT 20' DIA.
400 H.P.
2.4
DUST COLLECTOR
FLEX-KLEEN
200 H.P.
FROM PRE-
HOMOGENIZATION
STONE
BIN
TO BLENDING →
2.1
MILL - 2 COMPARTMENT
F.L. SMIDTH 4m DIA. X 7m
2200 H.P.
ADDITIVES

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 14/12/83
CHECKED DCS
DATE 20/09/84

FIGURE III
RAW GRINDING CIRCUIT
FLOW DIAGRAM

PLANT CANADA CEMENT LAFARG
ST CONSTANT, QUEBEC

PROJECT No. 20010

discharge elevator where it mixes with material from the mill and then to the air separator. The stone is dried in the separator by contact with hot gases supplied by an external heater and then is fed along with the separator rejects to the mill as fresh feed.

Supplementary raw materials, sand and iron, which constitute a small fraction of the total mill feed, do not need to be dried separately and are fed directly to the mill.

Raw mill #2 at St. Constant is a two compartment ball mill driven by a 2200 HP motor through reduction gears. Mill feed material passes through the mill by fluid action, intermingling with the ball charge and undergoing comminution. The mill discharge material is conveyed by elevator to the separator where classification takes place by gravitational and centrifugal forces. Coarse particles fall or are thrown into a central "rejects" cone and are returned to the mill. The fine particles are swept to the outer cone.

Mill air sweep is accomplished by an exhaust fan. Dust laden air passes from the mill and is carried through a duct to a baghouse dust collector before being exhausted. Drying gases from the separator also pass through the baghouse. Collected dust is returned to the ground product.

The equipment list for raw grinding is presented in Table 3.

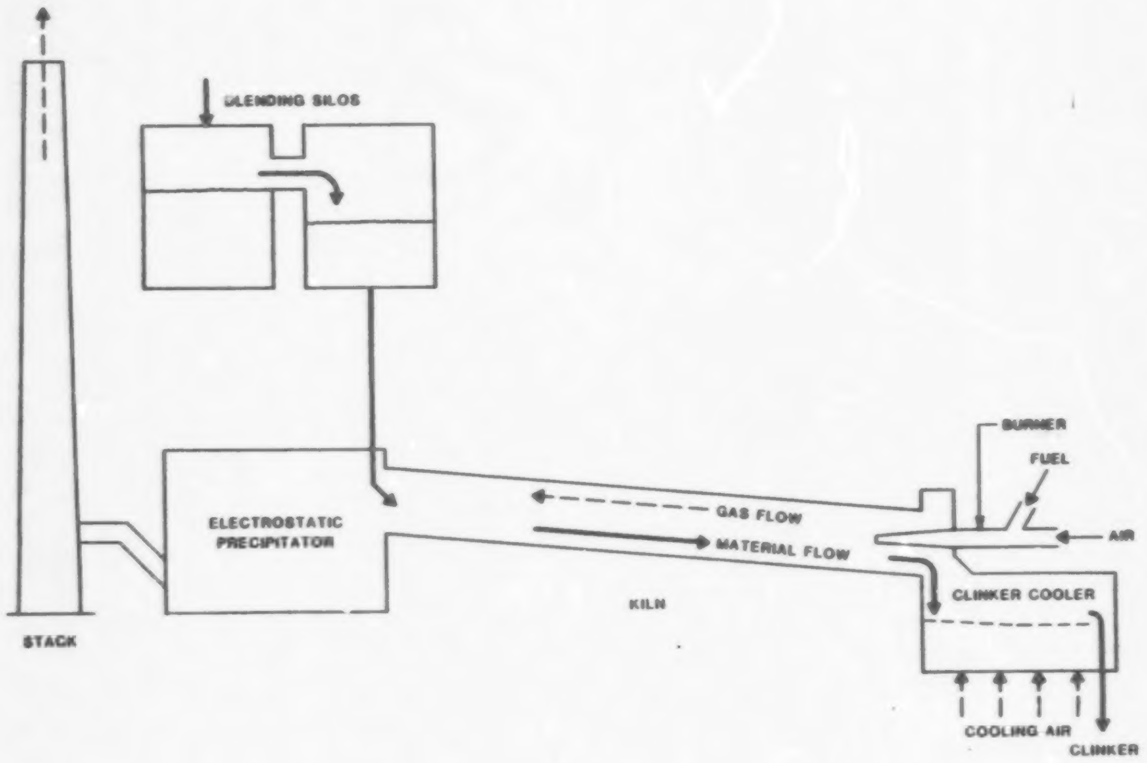
TABLE 3 - Raw Grinding - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
2.1	Mill - 2 Compartment F.L. Smidth 4 m dia. x 7 m	2200	4000	310
2.2	Elevator - Rexnord	150	575	134
2.3	Separator Sturtevant 20' dia.	400	4160	54
2.4	Dust Collector - Flex-Kleen	200	575	176

Regular sampling and testing ensure the raw mix meets the chemical and physical targets. Chemical composition is determined by x-ray. Raw mix fineness is checked by sieve.

3.4 Burning

The heart of the cement making process is the rotary kiln (Fig. IV). The kiln is a metal tube lined with refractory material and installed on a system of rollers so that it can be turned, usually at the rate of 1-1½ rpm. The two 4.6 x 122m kilns at St. Constant are termed long dry process since the kiln feed is in dry powder form and all steps of pyroprocessing take place in the kiln. Feed material is moved through the kiln by the rotary action and the fact that the kiln is sloped downwards toward the discharge end. The material passes counter-current to hot gases generated by fuel combustion at the discharge end, taking about 90 minutes to move from inlet to outlet.


BLENDING SILOS
STACK
ELECTROSTATIC PRECIPITATOR
GAS FLOW
MATERIAL FLOW
KILN
BURNER
FUEL
AIR
CLINKER COOLER
COOLING AIR
CLINKER

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 16/12/83
CHECKED DCS
DATE 20/09/84

FIGURE IV
KILN CIRCUIT
FLOW DIAGRAM

PLANT CANADA CEMENT LAFARGE
ST CONSTANT, QUEBEC

PROJECT No. 20010

As kiln temperature rises, residual moisture in the kiln feed is driven off prior to calcining, where the limestone decomposes to carbon-dioxide and lime. The temperature is further raised until part of the material becomes liquid and the mineral compounds are formed. This is termed clinkering. The temperature then drops slightly before the clinker is discharged from the kiln so that the material solidifies into nodules. The clinker drops from the kiln into the cooler where air is forced through the bed of clinker. Part of the cooling air is recovered and used for combustion in the kiln. The cooled clinker is transferred to storage or directly to finish grinding.

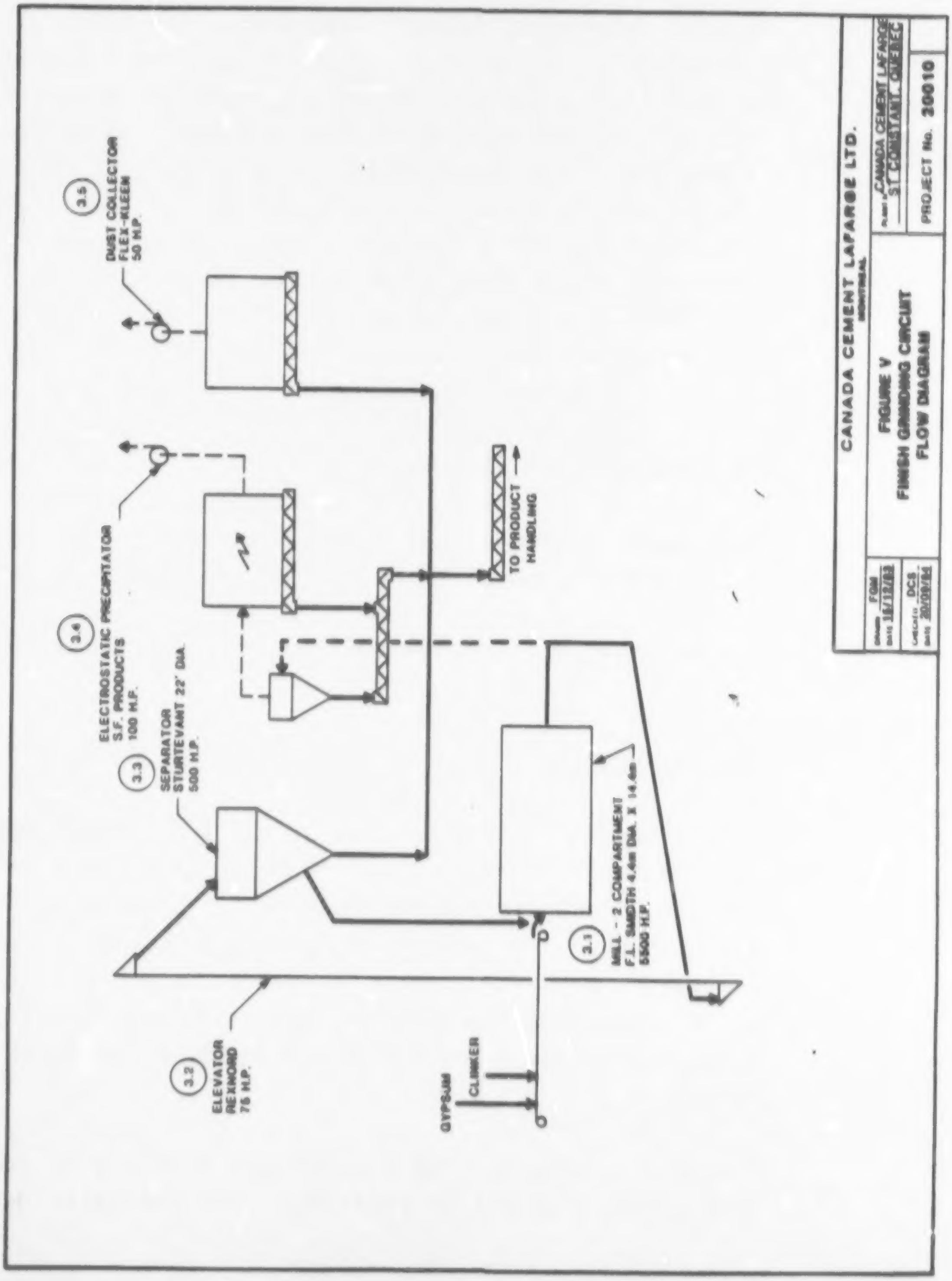
Dust-laden gases leaving the feed-end of the kiln are cleaned by electrostatic precipitation before being exhausted. Under proper operation of kiln and precipitator, virtually all dust is removed from the kiln gases.

The kilns at St. Constant can be fired with gas or Bunker "C" oil.

3.5 Finish Grinding

Finish mill #2 at St. Constant is a 2 compartment ball mill (Fig. V) driven by a 5500 HP motor through reduction gears. Clinker is fed directly to the mill by weighfeeder and a controlled amount of gypsum is added. The mill discharge goes via bucket elevator to an air separator which classifies the material into a product specification fine stream, and a reject stream which is returned to the mill.

The mill air sweep goes through the mill and is ducted to 2 cyclones arranged in parallel. The partially de-dusted


CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE V
FINISH GRINDING CIRCUIT
FLOW DIAGRAM
PLANT CANADA CEMENT LAFARGE ST CONSTANT, QUEBEC
PROJECT No. 20010
DRAWN FGM
DATE 18/12/83
CHECKED DCS
DATE 20/09/84
3.1
MILL - 2 COMPARTMENT
F.L. SMIDTH 4.4m DIA. X 14.4m
5500 H.P.
3.2
ELEVATOR
REXNORD
75 H.P.
3.3
SEPARATOR
STURTEVANT 22' DIA.
500 H.P.
3.4
ELECTROSTATIC PRECIPITATOR
S.F. PRODUCTS
100 H.P.
3.5
DUST COLLECTOR
FLEX-KLEEN
50 H.P.
GYPSUM
CLINKER
TO PRODUCT HANDLING

air then passes through an electrostatic precipitator where it is cleaned before being exhausted.

The mill discharge temperature is regulated by water spray which also serves to adjust the relative humidity of the air before being passed to the precipitator. A baghouse dust collector de-dusts separator, elevator and air-slides. Dust from cyclones, electrostatic precipitator and baghouse is returned to the finished product. The equipment list for finish grinding is shown in Table 4.

TABLE 4 - Finish Grinding - Equipment List

EQUIPMENT		MOTOR		
No.	TYPE/MAKE/MODEL	HP	VOLTS	AMPS
3.1	Mill - 2 Compartment F.L. Smidth 4.4 m dia. x 14.4 m	5500	4000	778
3.2	Elevator - Rexnord	75	575	67
3.3	Separator - Sturtevant 22' dia.	500	4000	72
3.4	Electrostatic Precipitator S.F. Products	100	550	94
3.5	Dust Collector - Flex-Kleen	50	575	46

Regular sampling and testing is done on the cement as it is produced. Chemical composition is determined by x-ray with special attention to SO_3 content which is adjusted by gypsum addition. The Blaine fineness and percent passing 45 um is also checked regularly.

The finished product is conveyed to the storage silos and from these can be transferred to the bulk loading silos or packing machines for bagging.

4.1 Crushing

4.11 Electrical Measurements

Power levels in kilowatts for the crushing department (Table 5) were calculated from measured amp, voltage and power factor. The results show the feeder is reasonably well loaded electrically and, at the maximum, is drawing nearly full-load power. The crusher, on average, is operating well within its power limit and, even at maximum, does not closely approach its capacity.

TABLE 5 - Crushing - Measurements

		MOTOR HP	POWER OBSERVATIONS - KW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
1.1	Feeder	75	52	40	46
1.2	Crusher	700	450	369	404
1.3	Screens #1	25	13	13	13
	#2	25	12	12	12
1.4	Dust Collector	60	54	54	54

Both screens are operating at steady power levels and are well under electrical capacity. The dust collector fan, although operating steadily, was shown by the measurements to be operating above its power limit. However, this does not appear to be causing any problems for the over-all crushing operation.

4.12 Flowrates

The production rate of the crushing department varies depending on the moisture content of the quarry-run stone. Plant experience has shown that the production rate varies from 400 tph under damp, muddy conditions to 425 tph under dry conditions. At the time of the plant visit, conditions were wet and the production rate was taken as 400 tph.

4.13 Crusher Feed Size Distribution

Due to the size of crusher feed, no sample was taken. However, the material was observed during the visit and estimated to have the following characteristics:

Maximum size	:	1.25 m
Average size	:	20 cm
Minus 4 cm	:	30%

Stone from the crushing circuit is the major feed constituent to the raw mill.

Much of the fine material in the crusher feed consists of overburden material which is quarried with the stone.

4.14 Specific Energy Consumption

The specific power consumption of the crushing department (Table 6) as determined by the measurements is modest. Because the large size of the feed, the ultimate fineness achieved in crushing (-19 mm) is not great.

TABLE 6 - Limestone Crushing
Specific Power Consumption

Flowrate: 400t/h

	kWh/tonne	%
Comminution	1.01	76.5
Auxiliaries	0.31	23.5
Total	1.32	100.0

Although a major portion of the electrical consumption is due directly to comminution, a significant fraction of the consumption arises from auxiliaries. The main cause of this is the dust collector fan which was determined to be operating above its capacity.

4.2 Raw Grinding

4.21 Electrical Measurements

Observed power levels for the raw mill (Table 7) show that the mill motor is operating at a very steady level and practically at its limit. The elevator, while showing some variation, is operating well under capacity. The separator motor shows some variation but does not approach its limit. The dust collector fan varies somewhat in its power level but remains easily within its capacity.

TABLE 7 - Raw Grinding - Measurements

		MOTOR HP	POWER OBSERVATIONS - KW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
2.1	Mill	2200	1635	1634	1635
2.2	Elevator	150	59	52	55
2.3	Separator	400	122	117	119
2.4	Dust Collector	200	97	90	93

Variation in power level of the elevator is related to amount of material conveyed and, since the elevator discharges to the separator, fluctuation in elevator power level is linked to fluctuations in the separator. Since the raw milling system must also dry material as well as grind, the air passing through the dust collector and fan will contain a significant amount of moisture and may affect the power level of the fan since the air density varies with moisture content.

4.22 Flowrates

Stone and additive materials to raw mill #2 are metered by weigh-feeders with each material passing through its own feeder. The total flowrate of all materials, 116.4 t/h, was taken as the production rate of the mill system. The approximate proportions of materials to the raw mill are 90-95% stone, 2-4% coarse sand, 0.5-1.0% fine sand, and 2% iron as mill scale.

Material conveying equipment in the mill system consists of elevators and airslides. Therefore, no other material flowrates were estimated or established directly during the field work.

4.23 Grindability

Bond grindability testing (Table 8) was performed on the stone and coarse sand because they make up the major portion of the raw mix blend and are the hardest materials involved. The Hardgrove Index was determined for these materials as well as for fine sand and iron. The Bond Index was also calculated for all four materials from the Hardgrove results.

TABLE 8 - Raw Mill - Grindability Testing

MATERIAL	GRINDABILITY		
	BOND (kWh/Ton)	HARDGROVE INDEX	BOND (Calculated)
Limestone	10.86	60	10.48
Coarse Sand	20.77	37	16.27
Fine Sand	-	55	11.34
Iron	-	75	8.55

4.24 Chemical Analysis

Analyses of the various materials in the raw mill circuit (Table 9) were obtained from the plant laboratory during the field work.

TABLE 9 - Raw Grinding - Chemical Analyses

OXIDE	STONE	COARSE SAND	FINE SAND	IRON	RAW MIX
Si	8.54	93.62	78.63	5.68	14.01
Al	2.51	0.22	8.57	1.09	2.88
Fe	0.95	0.62	3.82	90.66	2.31
Ca	46.57	2.06	1.03	2.64	42.35
S	0.24	0.06	0.01	0.09	0.21
Mg	2.24	0.55	1.24	0.75	1.70
K	0.63	0.23	1.58	0.09	0.60
Na	0.24	0.02	1.67	0.21	0.19
Loss	37.81	2.48	2.44	-	35.70

The silica (Si) content of the two sands correlates with their respective grindabilities. The coarse sand, having silica in excess of 90%, shows the higher grindability while the fine sand, with silica less than 80%, has a lower grindability, as indicated by the calculated Bond Index. The two sands make up a minor portion of the raw mix blend and, therefore, their effect on work required by the raw mill is not significant.

4.25 Particle Size Distribution

Sieve and sedigraph analyses on raw materials and raw mill circuit (Table 10) show all mill feed is -25 mm. The stone and coarse sand are similar in size range with the greatest difference in their distributions occurring in the mid-sizes. The fine sand shows a fairly narrow size distribution. The iron ranges up to 25 mm particle size but also has a significant amount of particles finer than the other raw materials.

TABLE 10 - Raw Mill #2 - Size Distributions (% Passing)

SIZE	STONE	COARSE SAND	FINE SAND	IRON	MILL DIS-CHARGE	SEPAR-ATOR REJECTS	SEPAR-ATOR FINES
25.4 mm	100	100	-	100	-	-	-
19.0	97.9	96.4	-	98.4	-	100	-
12.7	81.8	83.1	-	97.2	-	92.3	-
9.5	67.7	73.1	100	96.3	100	89.0	-
4.75	46.6	53.6	97.9	92.4	99.9	82.4	-
2.36	32.1	44.2	94.7	69.6	98.7	76.9	-
1.18	21.7	40.1	87.3	51.6	96.2	71.6	-
600 µm	14.5	37.0	70.7	42.1	89.9	63.9	100
300	9.4	24.8	39.6	36.1	75.2	48.2	99.5
150	5.9	8.5	16.6	30.7	51.1	25.9	92.7
75	3.6	3.8	7.0	24.7	35.0	13.8	79.4
45	-	-	-	-	30.5	11.7	69.6
30	-	-	-	-	27.0	11.0	62.0
20	-	-	-	-	23.5	10.0	52.5
10	-	-	-	-	17.0	7.5	37.0
6	-	-	-	-	13.0	5.5	27.0
2	-	-	-	-	6.0	3.0	12.0

The mill discharge material ranges from about 10 mm to -2 µm fraction. The presence of fresh unground stone in the separator reject stream is because stone is passed through the separator for drying before going to the mill.

The fineness target for the raw mix is 80% passing 75 µm.

4.26 Circulating Load and Separator Performance

The circulating load of the raw mill system and the separator partition curve (Fig. VI) were determined from the granulometry of the various system streams.

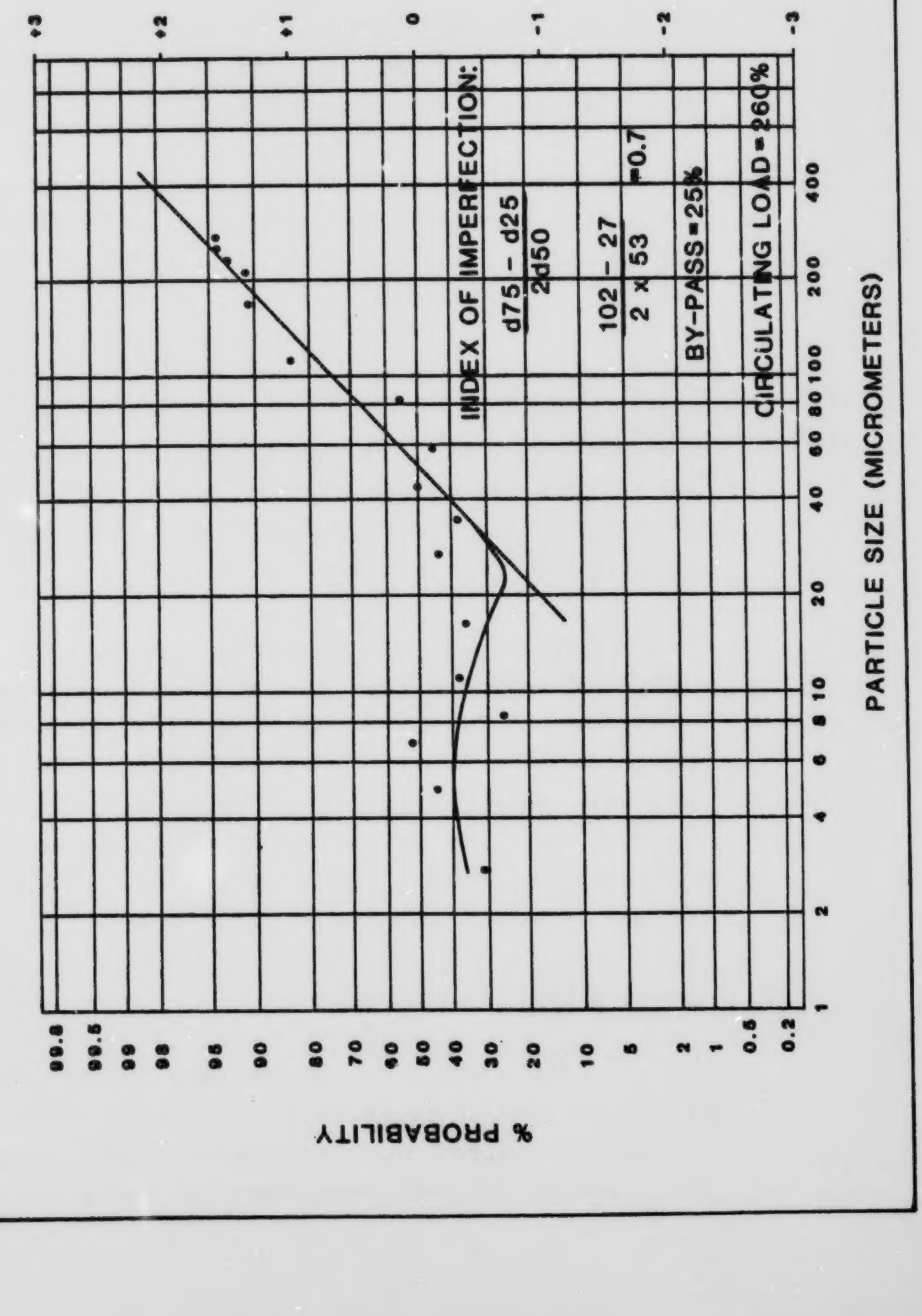
For the raw mill, allowance was made for the fact that fresh stone is present in the separator feed and reject streams. The circulating load, which is the ratio of material circulating in the system, was calculated as follows:

$$\boxed{\text{Circulating Load} = \frac{\text{Rejects} - \text{Stone}}{\text{Fresh Feed}}}$$

The reported circulating load of 260% is considered appropriate for this mill system. The electrical measurements indicate that the discharge elevator could carry a higher circulating load. However, this is not required, considering the grindability of the materials and the required fineness of the raw mix.

The separator partition curve provides a general indication of how well the separator is doing its job. The ideal classifier separates the feed material about a "cut

Figure VI - RAW MILL No.2 SEPARATOR PARTITION CURVE



point", i.e., particles above a certain size are rejected. However, in practice, the air separator is not a "perfect" classifier and actually separates particles about a "distribution" of sizes rather than a single size. The partition curve is a plot of probability of a particle of a given size ending up in the reject stream.

On the ascending part of the curve, particles are being classified according to their size. The "imperfection" of the separator is related to the slope of the curve with the "ideal" classifier having a vertical line from 0-100% probability at the "cut point" and an "index of imperfection" of zero. As the slope of the curve flattens, the index increases. On the "flat" part of the curve, particles have more or less equal probability of ending up in the rejects regardless of their size. This probability is called "by-pass" and is taken as the probability at the lowest point on the curve.

The index of imperfection and by-pass for raw mill #2 separator indicate that the separator is performing relatively well. The low by-pass of fine particles is related to the fact that coarse unground stone is in the separator feed and passes directly to rejects, thereby displacing some of the fine particles from the reject stream. The moderate circulating load also reduces feed to the separator and improves separation efficiency.

4.27 Specific Energy Consumption

The specific power consumption rate for raw mill #2 (Table 11) shows that a relatively high percentage of the total energy is required for comminution itself despite the fact that several hundred horsepower is installed on auxiliary devices; elevator, separator, and dust collector fan. However, electrical measurements indicate that the mill motor is running at capacity, while auxiliary motors are operating significantly under capacity, partly due to moderate circulating load.

TABLE 11 - Raw Grinding
Specific Power Consumption

Production Rate: 116.4 t/h

	kWh/tonne	%
Comminution	14.0	85.9
Auxiliaries	2.3	14.1
Total	16.3	100.0

4.3 Finish Grinding

4.31 Electrical Measurements

The electrical measurements for finish mill #2 (Table 12) show that the mill motor is operating at capacity. Both elevator and separator kilowatts indicate that equipment is operating steadily and within its electrical capacity.

Both precipitator and dust collector fans are well under their electrical capacity and drawing steady loads. High voltage energy to the precipitator electrodes is considered as part of auxiliary energy. The electrodes cycle through a programmed sequence of collecting and cleaning. The condition of the electrodes, material build-ups and short circuits affects the power level of the high voltage.

TABLE 12 - Finish Grinding - Measurements

		MOTOR HP	POWER OBSERVATIONS - KW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
3.1	Mill	5500	4305	4301	4303
3.2	Elevator	75	50	50	50
3.3	Separator	500	306	304	305
3.4	Precipitator	100	45	45	45
	High Voltage #1		3	3	3
	#2		7	7	7
3.5	Dust Collector	50	30	30	30

4.32 Flowrates

Clinker and gypsum to finish mill #2 are metered through individual weighfeeders. The total flowrate of clinker and gypsum was taken as the production rate of the mill system. The production rate for finish mill #2 during the field work was calculated as 95 tonnes per hour. Dust flowrate from the electrostatic precipitator and cyclones had previously been determined from plant records as 15 tonnes per hour. This material is returned to the finished product and effectively by-passes the separator.

4.33 Grindability

Results of Bond and Hardgrove grindability testing (Table 13) show good agreement between measured Bond Work Index and the Bond Index calculated from Hardgrove measurements. The Hardgrove Index for gypsum indicates the most easily ground of all materials tested. The Bond test was not performed on gypsum, due to its low grindability index and also the fact that it is a minor constituent in the feed to the finish mill.

TABLE 13 - Finish Mill - Grindability Testing

MATERIAL	GRINDABILITY		
	BOND (kWh/Ton)	HARDGROVE INDEX	BOND (Calculated)
Clinker	12.01	54	11.54
Gypsum	-	98	6.71

4.34 Chemical Analysis

Chemical analyses of materials in the finish mill (Table 14) were provided by the plant laboratory.

TABLE 14 - Finish Grinding - Chemical Analyses

OXIDE	CLINKER	GYPSUM	CEMENT
Si	21.72	5.41	21.45
Al	4.47	1.50	4.43
Fe	3.58	0.50	3.50
Ca	64.00	31.50	62.78
S	1.16	43.38	3.37
Mg	2.64	0.93	2.44
K	0.93	0.15	0.98
Na	0.29	0.01	0.32
Loss	0.20	16.48	0.95

4.35 Particle Size Distribution

Clinker and gypsum mill feed (Table 15) are -25 mm and -19 mm, respectively. Both contain -150 µm material. Size distribution of various process streams in finish mill #2 system (Table 16) reveal that the separator feed is slightly coarser than the mill discharge due to finer material bypassing into the de-duster. Separator rejects are only slightly coarser than separator feed with the difference diminishing in the smaller sizes. Separator fines have a relatively narrow size distribution, while dust from the baghouse collector is very similar to separator fines in size distribution. Dust from the cyclones and precipitator is significantly coarser than separator fines or baghouse dust, particularly in the mid-sizes. The finished product, which includes separator fines plus returned dust, is somewhat coarser than the separator fines.

TABLE 15 - Finish Mill #2 Size Distributions

SIZE	% PASSING	
	CLINKER	GYPSUM
25.4 mm	100	-
19.0	99.1	100
12.7	96.5	83.4
9.5	93.7	72.7
4.75	83.3	57.8
2.36	68.2	47.9
1.18	55.2	40.4
600 µm	45.8	34.1
300	35.9	26.6
150	19.9	17.1

TABLE 16 - Finish Mill #2 Size Distributions (% Passing)

Size	Mill Discharge	Separator Feed	Separator Rejects	Separator Fines	Cyclones & Precipitator	Dust Collector	Finished Product
1.18 mm	100	-	-	-	-	-	-
600 µm	99.9	100	100	-	-	-	-
300	95.9	95.6	94.6	-	-	-	-
150	86.2	83.6	80.5	100	100	100	100
75	74.1	69.1	66.8	97.5	98.1	97.2	96.7
45	53.0	51.8	47.4	86.3	80.1	86.5	85.0
30	40.0	40.2	34.0	72.0	62.0	70.0	69.0
20	30.0	32.0	25.0	58.0	47.0	56.0	54.0
10	20.0	21.5	18.0	36.0	30.0	35.5	34.0
6	13.0	15.0	13.0	24.0	22.5	24.0	22.0
2	5.5	6.0	6.0	8.0	11.0	11.0	8.0

4.36 Internal Sampling

A total of 24 samples of material were taken from both compartments inside finish mill #2 after a crash stop (Fig. VII). Blaine and +850 µm (No. 20 sieve) testing was done. The results (Table 17) were averaged for each cut across the mill and are presented graphically in Figure VIII.

TABLE 17 - Finish Mill #2 - Internal Sampling Results

SAMPLES	AVERAGE	
	Blaine m^2/kg	+850 µm
1st Compartment		
1, 2, 3	148	6.3
4, 5, 6	137	7.8
7, 8, 9	138	7.1
2nd Compartment		
1, 2, 3	140	4.4
4, 5, 6	149	2.8
7, 8, 9	160	2.6
10, 11, 12	173	3.4
13, 14, 15	180	6.1

Figure VII - FINISH MILL No.2
INTERNAL SAMPLING PATTERN

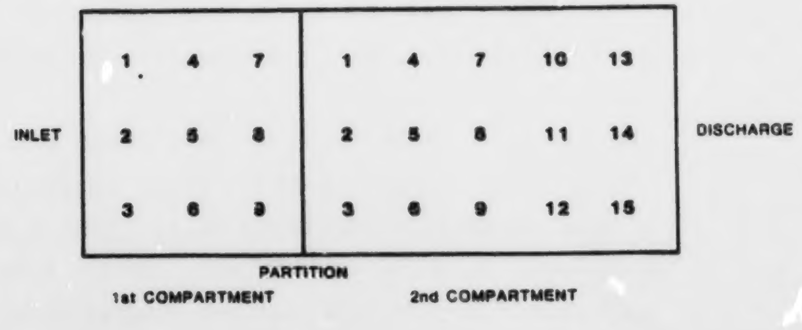
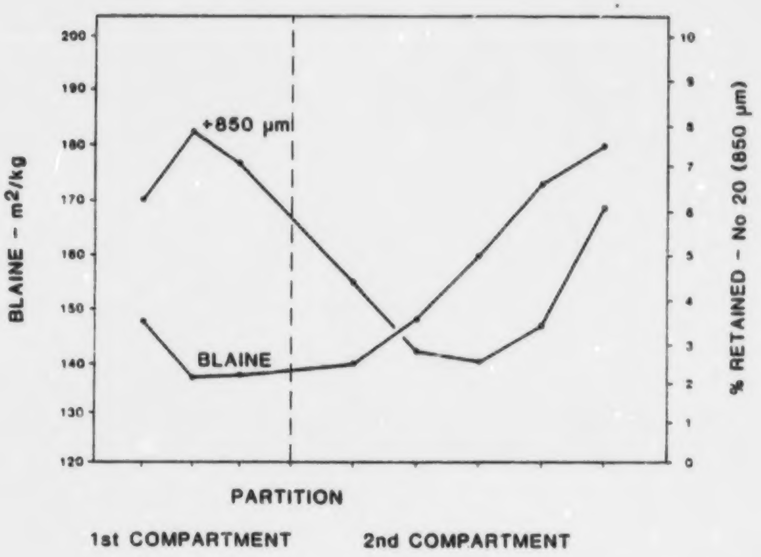

INLET
DISCHARGE
PARTITION
1st COMPARTMENT
2nd COMPARTMENT
1
4
7
2
5
8
3
6
9
1
4
7
10
13
2
5
8
11
14
3
6
9
12
15

Figure VIII - FINISH MILL No.2
INTERNAL SAMPLING



The results show a drop in Blaine with a corresponding increase in +850 µm material through the first half of the first compartment. This may be the result of some reject material from the separator flushing into the mill after the crash stop.

The Blaine rises gradually through the rest of the first compartment and then rises more rapidly through the second compartment, leveling off somewhat near the end of the mill. The +850 µm material decreases through the partition and first half of the second compartment and then shows a substantial rise again toward the end of the mill.

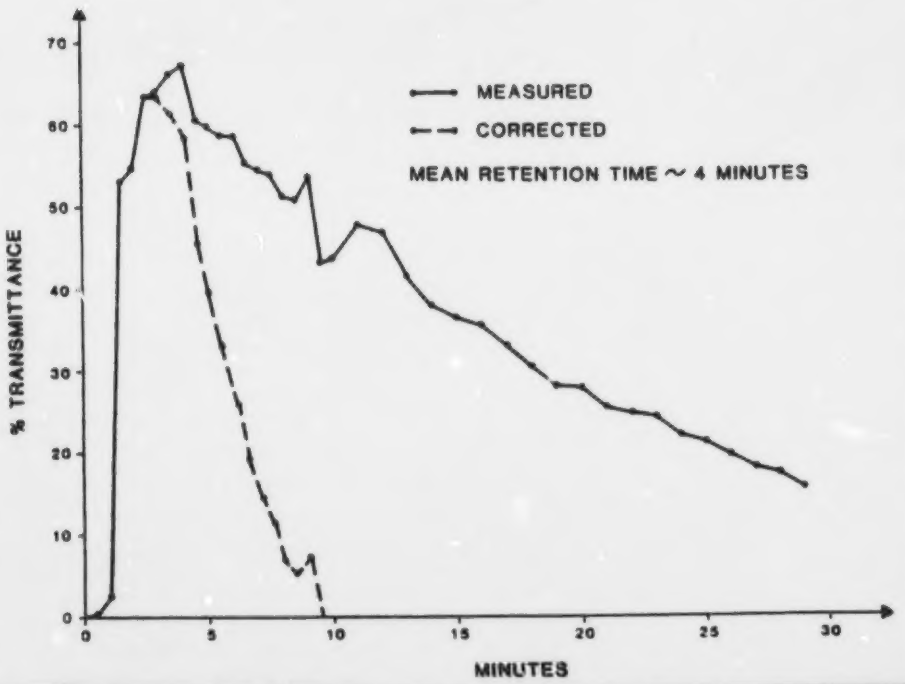
The results indicate a significant amount of coarse grinding taking place in the first compartment and first half of the second compartment with only a modest corresponding increase in fine particles. More fine grinding is shown to take place in the second compartment, as expected.

The +850 μm data confirms the poor condition of the partition between the two compartments. In a physical inspection during the internal sampling, some openings in the partition were found to be excessive and requiring repair. The result is that some coarse material passes through the partition to the second compartment and tends to accumulate near the discharge end of the mill resulting in the increase in coarse material in that area.

4.37 Residence Time Distribution

Results of residence time testing using a dye tracer are shown graphically in Figure IX. The results are plotted as % transmittance, which is proportional to tracer concentration in the sample, against time. At time zero, a quantity of tracer is introduced as a pulse to the mill inlet.

Figure IX - FINISH MILL No.2
RETENTION TIME DISTRIBUTION



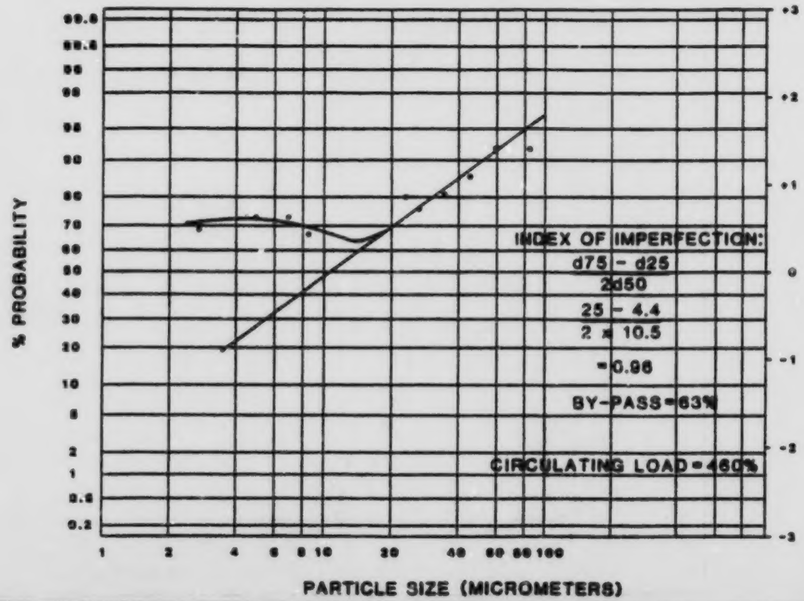
The solid curve in Figure IX depicts the results as obtained directly from the mill, with tracer concentration rising rapidly to a peak and falling off gradually as tracer is eliminated from the system. The broken curve corrects for the re-cycle of tracer back to the mill through separator rejects.

The mean residence time is taken as that point on the corrected curve, which divides the area under the curve equally. For this mill, it was calculated to be about 4 minutes. Based on past experience with the mill, this residence time is somewhat high and, is probably a result of the partition. With insufficient coarse grinding in the first compartment, a build-up of coarse material occurs in the second compartment thereby impeding the overall material flow and increasing mean residence time.

4.38 Circulating Load and Separator Performance

Circulating load and separator partition curve (Fig. X) were determined for finish mill #2.

Figure X - FINISH MILL No.2 SEPARATOR PARTITION CURVE



Allowance was made, in calculating circulating load, for 15 tph of dust from the electrostatic precipitator and cyclones which by-pass the separator and go directly to finished product. The calculated circulating load was 460%, which is considered to be relatively high and this results in elevator and separator operating at quite high power levels.

The calculated partition curve for the separator shows an index of imperfection and by-pass which are both high. The high index of imperfection, corresponding to a relatively low slope, indicates a broad distribution of sizes around which the separator is classifying the feed material. The 63% by-pass of fine particles and the index of imperfection both indicate reduced separator efficiency.

Reduced separator efficiency may be a result of separator condition and/or feed rate. In this case, visual inspection of the separator during the plant visit showed that repairs were needed to selector blades, table and diaphram. The condition of the separator tends to lead to a higher circulating load while, at the same time, the excessively high circulating load tended to impair separator efficiency. Both factors, in this case, contribute to the result shown by the partition curve.

4.39 Specific Energy Consumption

Specific power consumption (Table 18) for finish grinding is higher than raw milling. This is due to the grindability of clinker and the required fineness of the finished product.

TABLE 18 - Finish Grinding
Specific Power Consumption

Production Rate: 95 t/h

	kWh/tonne	%
Comminution	45.3	90.8
Auxiliaries	4.6	9.2
Total	49.9	100.0

The cumulative power consumption of just over 75 kWh/tonne (Table 19) for the finished product incorporates calculated specific energies as well as a number of other factors. Allowance was made for the fact that only the stone is crushed at the quarry and additive materials are ground at the raw mill. The calcination step at the kiln wastes 35-36% by weight of the raw mix as CO_2. Therefore, about 1.5 tonnes of raw mix must be ground to produce one tonne of clinker. In finish grinding, about 5% of the feed to the mill is gypsum which is not otherwise processed at the plant.

Auxiliaries consume 12% of the total, with most auxiliary energy being required for classification and dust collection.

TABLE 19 - Finish Product
Cumulative Consumption

Comminution 88.8% - Auxiliaries 11.2%

	kWh/tonne	%
Crushing	1.9	2.4
Raw Grinding	24.2	31.9
Finish Grinding	49.9	67.7
Total	76.0	100.0

5. CONCLUSIONS

The St. Constant plant, which is a typical Portland cement manufacturing facility, has an energy intensive process. The largest energy consumer is pyroprocessing but electrical energy requirements for crushing and grinding and associated equipment is high. This results from the need to reduce large lime rock to a fine powder for the kilns and also to grind the resulting clinker nodules of higher grindability than the stone, to an even finer product. Also, the loss of over a third by weight of raw mix during calcining further increases the energy expenditure to produce a unit amount of finished product.

The unit energy expenditure for primary crushing of limestone was found to be quite modest. Also, with the crushing production rate curtailed by wet conditions at the time of the visit, the results may be somewhat higher than would be realized under dry, ideal conditions. The reduction of the stone at the primary crusher to a relatively coarse -19 mm results in the low unit energy requirement.

The grinding and associated energy requirement at the raw mill was much greater than primary crushing. This is due mainly to the fineness of the raw mix. Also, the presence of a small amount of high grindability silica sand contributes to the raw mill system energy requirement.

Analysis of separator performance according to granulometries of various system streams showed that the circulating load and separator efficiency are good. The separator partition curve has a good index of imperfection with low by-pass of fine particles. The low by-pass is also related to the use of the separator to dry the limestone entering the system. A significant portion of the rejects is composed of fresh, coarse stone. The relatively low circulating load of the raw mill system enhances separator efficiency. Generally, the raw mill #2 system was found to be performing well.

The unit electrical energy requirement of finish mill #2 was determined to be relatively high. This is due to the hardness of the clinker which comprises the majority of the mill feed and also the fineness specification of the finished product.

Inspection of mill internals as well as results generated from internal material sampling and retention time distribution, all indicate the unsatisfactory condition of the partition between compartments. Some excessively large gaps were observed in the partition and internal sampling results show a build-up of relatively coarse material in the second compartment, indicating that this material is entering the second compartment before being sufficiently ground in the first. The mean retention time was also found to be high due to the hold-up of the coarse material in the second compartment.

The circulating load of the system was found to be quite high. The calculated partition curve corresponded to a high index of imperfection and a high by-pass of fine particles to rejects. The results indicate low separator efficiency which is partly the result of high circulating load. Inspection of the separator during the field work showed the need for internal repair work, especially to selector blades and table.

The cumulative energy calculated to produce the finished cement takes into account specific comminution and auxiliary energies of the various departments, as well as other factors. The unit consumption is substantial and, considering the productive capacity of the plant, the potential for energy conservation is significant. Dust collection and classification are the main consumers of auxiliary energy in this process.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

Cements are finely powdered mixtures of inorganic compounds which, when mixed with water, undergo a chemical (hydration) reaction and harden; those which harden under water are termed hydraulic. The "Portland" cement now used worldwide in quantities of about 80 million metric tons annually is produced from raw materials comprised of some of the earth's most abundant elements. Cement when mixed with water, fine aggregate (sand) and coarse aggregate (gravel or crushed stone) forms concrete.

The origin of modern cements was the lime-based materials used by the Greeks and Romans who developed lime cements and mortars from calcined limestones. The calcined product, when mixed with reactive or pozzolanic materials such as volcanic ash, had binding properties superior to the gypsum plasters developed by the early Egyptians.

Further development of these simple cements occured between the first century B.C. and the third century A.D.; little further advancement took place until the late 18th century when it was observed that when some argillaceous limestones were calcined they gave a hydraulic cement and the naturally occuring mix of the appropriate materials became known as cement stone or rock. By modern standards, these products were only lightly calcined so as not to be too greatly densified by sintering and therefore easily ground.

Joseph Aspdin, who obtained a patent in 1824, is usually regarded as the inventor of modern Portland cement. His product, made by burning chalk with clay in a lime kiln and grinding the sintered product (clinker), was considerably inferior to the present day material. Two fundamental developments have improved on the early product: the introduction of gypsum, added when grinding the clinker, to act as a set retarder (c. 1890) and the use of higher burning temperatures to allow the production of higher lime content silicates which are necessary for more rapid strength development in concrete. Improvements were aided by the gradual replacement of vertical shaft kilns with the rotary kiln and the introduction of the ball mill.

World cement production has levelled off over the last three years at about 760 million tonnes per year.

TABLE 1 - World Production Summary

(Quantities in 1,000 metric tons)

YR.	EUROPE	USSR*	AFRICA	MIDDLE EAST	U.S. & CANADA	ASIA	AUST-RALIA	TOTAL WORLD
Production								
'82	276,550	124,000	29,600	41,400	141,550	258,750	6,400	761,100
'81	283,050	127,169	28,268	35,432	151,200	256,100	7,050	761,200
'80	290,600	124,800	25,475	30,177	153,800	250,888	5,560	765,500
Imports								
'82	8,350	254	12,850	31,700	7,900	12,250	550	73,600
'81	8,400	200	5,752	38,498	7,400	10,650	550	71,250
'80	9,300	523	8,542	11,569	8,700	11,452	120	49,683
Exports								
'82	40,750	2,221	2,348	1,202	4,200	22,750	400	71,650
'81	39,750	2,735	1,898	1,402	4,900	20,500	350	68,800
'80	34,600	3,245	1,831	2,435	5,450	17,252	247	61,815
Apparent Consumption								
'82	244,250	122,033	39,200	69,250	142,700	249,350	6,600	751,350
'81	251,350	124,634	35,654	63,696	151,350	248,000	7,250	757,300
'80	265,100	122,078	30,809	50,288	154,100	245,721	5,780	751,798
Apparent Consumption per capita (kg)								
'82	465	452	107	572	225	110	290	184
'81	472	466	98	564	242	111	320	189
'80	515	460	92	823	252	241	395	386

Source: World Statistical Review, December 1983, published by CEMBUREAU, The European Cement Association, Paris, France

* U.S.S.R. figures also included in Europe summary.

Exports in 1982 were in the order of 73 million tonnes, of which 54% came from 5 countries, Spain, Japan, Greece, South Korea and Turkey which have located large scale cement plants at deep water ports specifically for the export market.

TABLE 2 - Top World Cement Exporters

(Quantities in 1,000 metric tons)

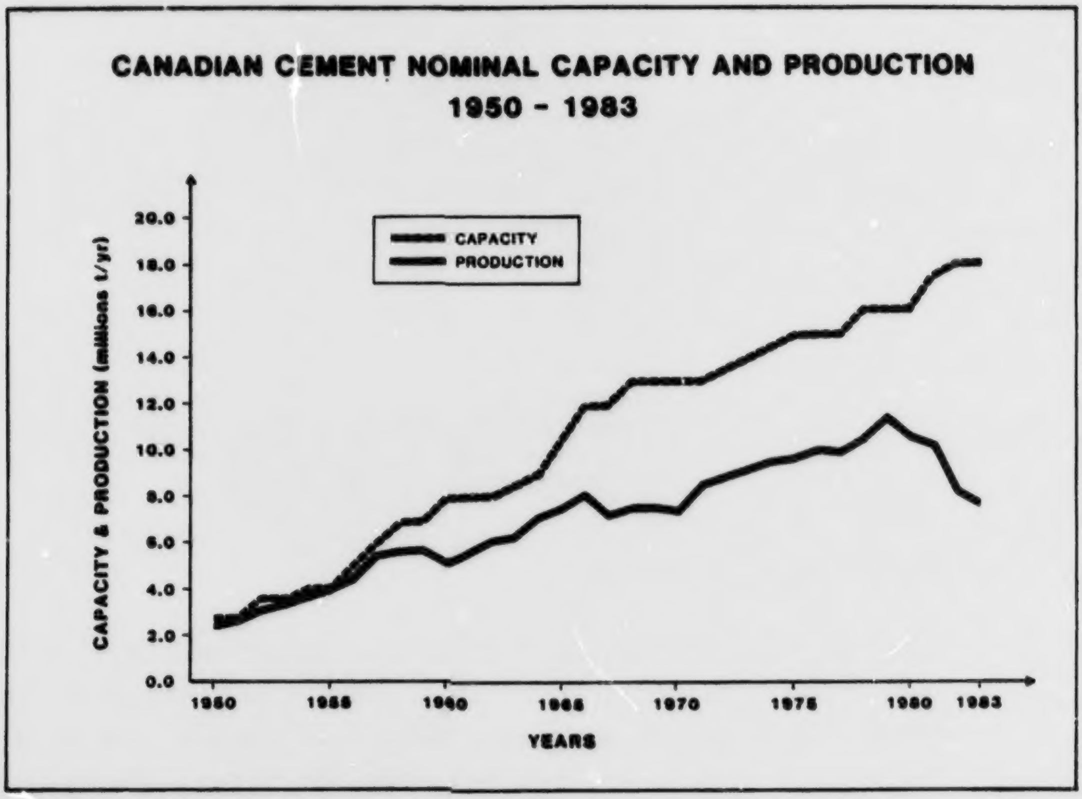
COUNTRY	VOLUME
Spain	11,835
Japan	11,173
Greece	6,887
South Korea	5,598
Turkey	4,186
France	3,059
Romania	3,000
Taiwan	2,683
U.S.S.R.	2,221
Canada	2,160
German Federal Rep.	2,159

Source: Lafarge Coppée

The Canadian Industry

Use of Portland cement in Canada began in 1887[3]. Although cement was imported initially, domestic production began in 1889. At that time, there were four cement plants in Canada located in the Montreal-Ottawa-Toronto area. Over the next few decades, the capacity to produce Portland cement grew rapidly, with several companies becoming involved and constructing new facilities. The resulting oversupply and competition created an unstable situation for the industry with little or no profits being made. This was resolved by consolidating the industry under the Canada Cement Company in 1909. Following this early expansion, growth of the cement industry in Canada was moderate until after the Second World War when, again, consumption of cement increased rapidly.

Expansion of capacity and replacement of old facilities with more efficient plants continued until the early 1980's when the economic recession severely reduced the demand for cement, leaving the industry with considerable excess capacity. This situation is expected to persist for a number of years.



CANADIAN CEMENT NOMINAL CAPACITY AND PRODUCTION
1950 - 1983

Source: Canada Cement Lafarge Ltd.

The relatively low value to weight ratio of cement has led to plants being sited as near as possible to their markets so that transportation costs can be minimized. The production capacity, as shown in Table 3, is spread across the country serving local markets by truck, rail and boat where possible and also supplying markets in the northern U.S. states.

TABLE 3 - Canadian Cement 1983 Capacity and Location

Company	Number of Kilns	Clinker Capacity	Grinding Capacity
ATLANTIC			
Canada Cement Lafarge Ltd	4	743	910
North Star Cement Ltd	1	130	250
QUEBEC			
Canada Cement Lafarge Ltd	2	910	950
Miron	2	838	1000
St. Lawrence Cement	6	1599	1625
Ciment Québec	1	840	449
ONTARIO			
Canada Cement Lafarge Ltd	3	1321	1612
Lake Ontario Cement	4	1442	750
St. Lawrence Cement	3	2000	1986
St. Mary's Cement	5	1593	1590
PRAIRIES			
Canada Cement Lafarge Ltd	5	1635	2113
Genstar Cement	6	1723	1597
BRITISH COLUMBIA			
Canada Cement Lafarge Ltd	3	635	796
Genstar Cement	1	950	1042
TOTAL	45	16,359	16,670

Source: Portland Cement Association

Involvement of most cement producers does not end with the manufacture of cement. Companies tend to be integrated into the concrete and related construction material industries. Cement companies supply ready-mix concrete, aggregates, and pre-formed concrete products. Because the primary consumption of cement is in the construction industry, sales for the cement industry is directly linked to the level of construction activity.

Research by the cement industry is aimed at improving the efficiency of the manufacturing process as well as increasing the uses of cement and concrete in various applications. The cement manufacturing process is energy intensive with over 80% of the energy being consumed at the pyroprocessing stage. Research is being carried out to improve thermal efficiency and to find cheaper energy sources. Many plants are now set-up to burn several fuels depending on process requirements and fuel costs. Research is being conducted on raw and finish grinding to optimize power consumption.

The Cement Manufacturing Process

The manufacture of Portland cement is essentially the production of calcium silicates from limestone and a silicate material such as clay or shale. The reaction is accomplished by pyroprocessing (heat-treating) a finely-pulverized mixture of the correctly-proportioned quantities of limestone and shale.

The chemical reactions involved are summarized in Table 4.

TABLE 4 - Chemistry of the Pyroprocess

Limestone ($CaCO_3$) $\xrightarrow{900°C}$ $CaO + Co_2$ gas

Clay silicates, Aluminates, etc. 900°C $SiO_2 + Al_2O_3 + Fe_2O_3$

$2\,CaO + SiO_2 \longrightarrow$	1200°C	Ca_2SiO_4	approximately 75% of clinker
$Ca_2SiO_4 + CaO \longrightarrow$	1400°C	Ca_3SiO_5	
$3CaO + Al_2O_3 \longrightarrow$	1300°C	$Ca_3Al_2O_6$	approximately 20% of clinker
$Ca_3Al_2O_6 + CaO + Fe_2O_3 \longrightarrow$	1300°C	$Ca_4Al_2Fe_2O_{10}$	

The net reaction is strongly endothermic (requiring heat). The iron and alumina compounds form liquid phases during the clinkering process and thereby act as a flux.

There are two main cement manufacturing processes:

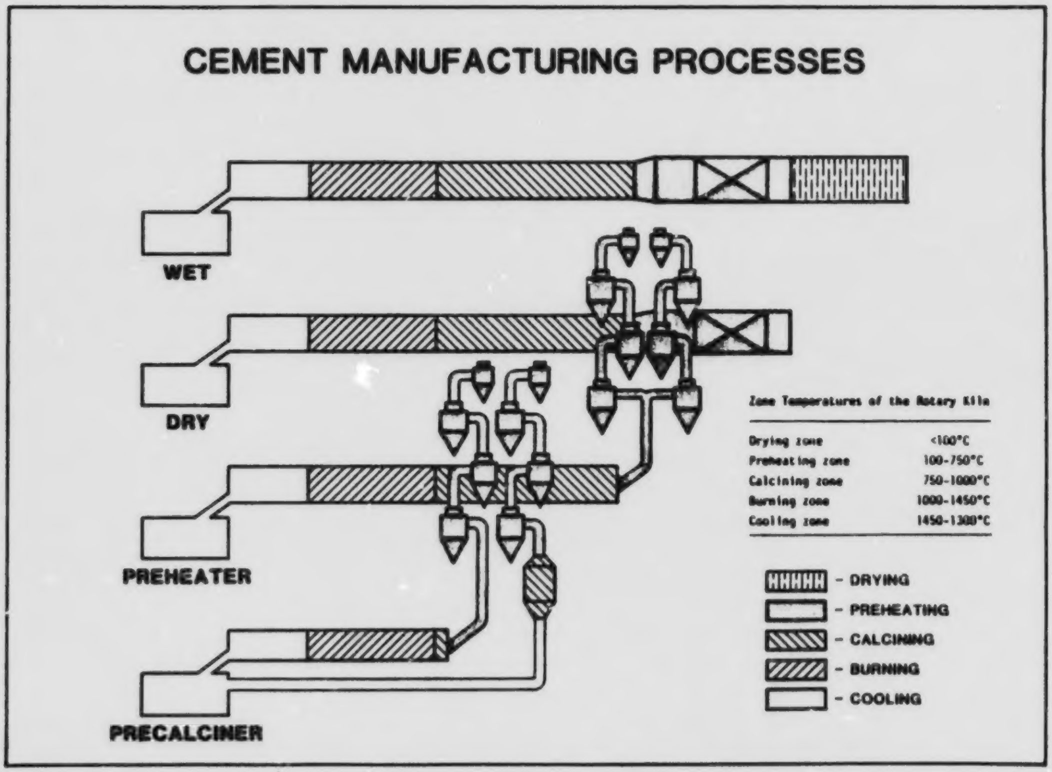
- **wet**, where the raw materials are ground to give a slurry of 30-35% water, which is pumped to the kiln. Because of its thermal inefficiency, this process is gradually being phased out;
- **dry**, where the raw feed is ground and fed to the kiln dry.

Variations of the dry process are the preheater and precalciner technologies, in which the raw material is preheated and precalcined in suspension before entering the kiln. The approximate heat consumption of the various processes is as follows.

PROCESS TYPE	GJ/t CLINKER
Wet	5.0 - 6.0
Long Dry	3.6 - 4.6
Preheated Precalciner	3.5 - 4.3

The pyroprocess by which clinker is formed involves temperatures in the material of up to 1450°C. To achieve this, a flame temperature greater than 2700°C is needed. These high temperatures are normally generated by burning gas, oil or pulverized coal.

The location of the different zones in the kiln is shown in the diagram below for the different systems. The kilns shown are all for the same production rate, so the figure clearly illustrates the decrease in physical size as development makes the manufacturing process more efficient.



CEMENT MANUFACTURING PROCESSES

WET
DRY
PREHEATER
PRECALCINER
HHHHH - DRYING
- PREHEATING
- CALCINING
- BURNING
- COOLING

Zone Temperatures of the Rotary Kiln	
Drying zone	<100°C
Preheating zone	100-750°C
Calcining zone	750-1000°C
Burning zone	1000-1450°C
Cooling zone	1450-1300°C

Source: Della M. Roy, J. Educational Modules for Materials Science & Engineering 1981, Vol. 3, No. 4, p. 631.

Chemical and Physical Characteristics

The performance of a cement is controlled by a combination of physical and chemical characteristics.

The most important physical characteristic of cement is its fineness; the more finely ground, the more reactive the cement is; the more reactive, the greater the strength development. The data below shows the relation of fineness, as measured by the Blaine permeability method, and strength development.

PRODUCT	BLAINE M^2/Kg	COMPRESSIVE STRENGTH M Pa at (days)			
		1	3	7	28
Normal Portland	374	-	23.1	29.3	37.4
High Early Strength	550	24.6	35.2	-	47.7

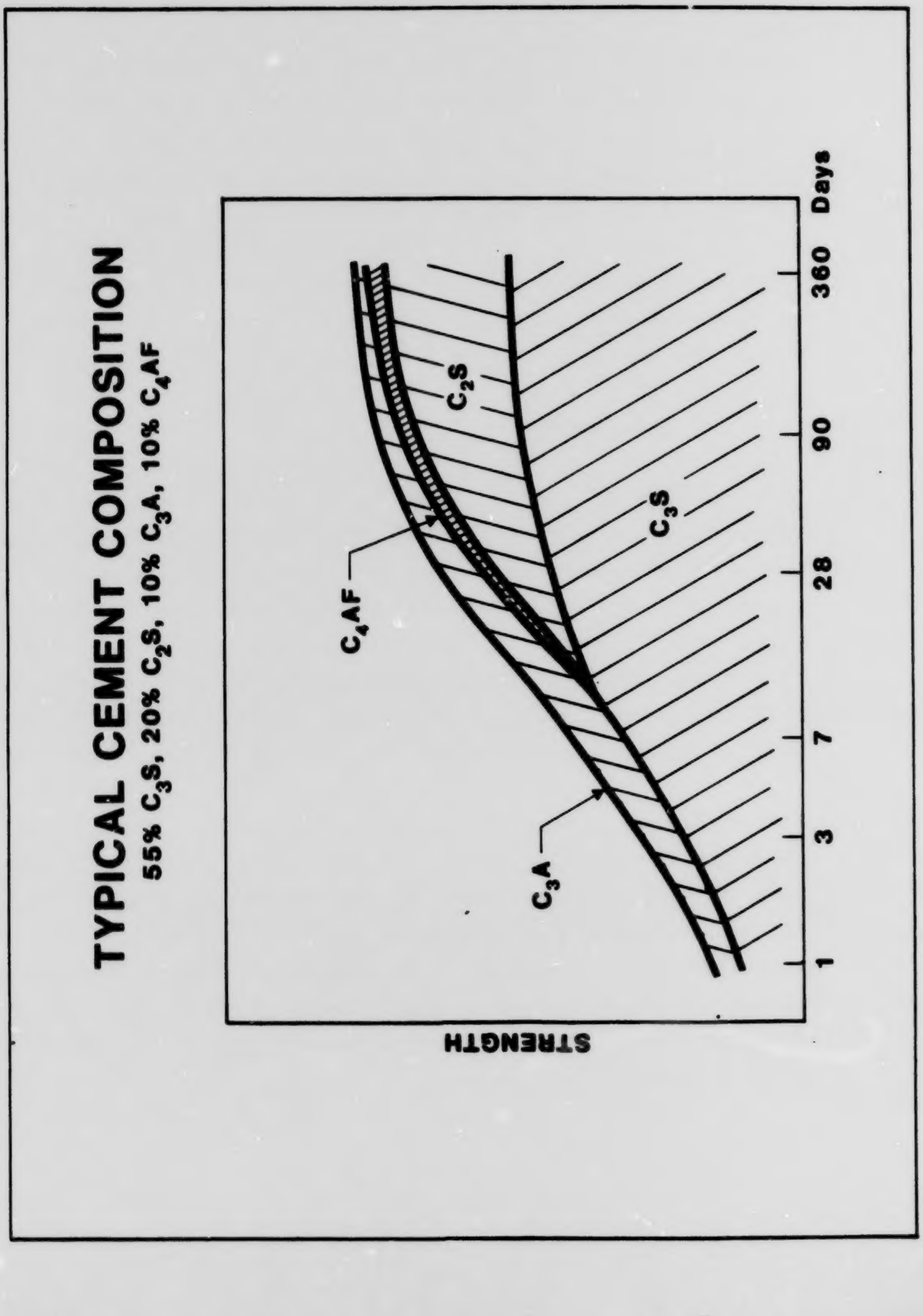
The four major chemical compounds and their principal properties are summarized in Table 5.

TABLE 5 - Properties of the Major Constituents of Portland Cement Clinker

CLINKER CONSISTS OF:	C_3S +	βC_2S +	C_3A +	C_4AF
Idealized chemical composition	Tricalcium silicate, $3CaO.SiO_2$	Dicalcium silicate, $2CaO.SiO_2$	Tricalcium aluminate, $3CaO.Al_2O_3$	Tetracalcium aluminoferrite, $4CaO.Fe_2O_3.Al_2O_3$
"Impure" phase equivalent	Alite	Belite	C_3A-alkali solid solution	Ferrite phase solid solution
Rate of hydration	Rapid (hours)	Slow (days)	Instantaneous	Very Rapid (minutes)
Heat of hydration	Medium: ~500 J/g	Low: ~250 J/g	Very High: ~850 J/g	Medium: ~420 J/g
Remarks	Characteristic constituent of Portland cements.		Unstable in water, sensitive to sulphate attack.	Imparts to the cement its characteristic grey color.

* Note the special formula abbreviation scheme used universally by cement chemists. Each oxide (a mole of CaO, Al_2O_3, Fe_2O_3, SiO_2, SO_3) is represented by a letter C, A, F, S, or $\bar{S}$, respectively. The latter, SO_3, is added usually as gypsum, $C\bar{S}H_2$, to the clinker to make the cement, and is important in controlling hydration of C_3A and C_3S.

Most of the strength of cement is from hydration of the di- and tricalcium silicates. The latter contributes to early strength development while the former contributes after about 10 days. The role of tricalcium aluminate and tetracalcium aluminoferrite are not well defined but are believed to act as shown in the graph overleaf.



TYPICAL CEMENT COMPOSITION

55% C_3S, 20% C_2S, 10% C_3A, 10% C_4AF

Chemical Requirements

The chemical requirements for cement tend not to be very strict, since it is known that cements with quite different chemical compositions may have suitable physical behaviour. Generally, the chemical requirements simply specify the maximum amounts of certain impurity oxides, such as MgO, SO_3, Na_2O, and K_2O. In addition, for certain types of cement such as low heat cements or sulphate resistant cements, there may be limitations on the contents of the four major cement constituents (C_3S, C_2S, C_3A, C_4AF).

Physical Properties

The **fineness** of cement can have a considerable effect on the behavior of cement during hydration. Of greatest importance, the rate of hydration increases with increasing fineness, leading to both a higher rate of strength gain and a higher rate of evolution of heat. In addition, finer particles will be more completely hydrated than coarser particles, because hydration takes place at the surface of the cement particles, forming a zone of reaction products which hinders further hydration.

There are two parameters that may be used to describe fineness: the specific surface of the cement particles (i.e., the summation of the surface areas of all of the cement grains in 1 kg of cement), and the particle size distribution. The general practice is to use only the specific surface area (Blaine) to quantify cement fineness, even though cement with quite different particle size distributions may have the same specific surface area.

Physical Properties of Cement Pastes (Cement + Water)

Consistency: Most commonly, the normal consistency is defined in terms of the Vicat apparatus, in which the penetration of a special needle into the cement paste under a given weight is determined. This test is a measure of the plasticity of the cement paste.

Time of setting: Two setting times are generally defined; initial set, which indicates that the paste is beginning to stiffen and final set which indicates that the paste has hardened to the point at which it can sustain some load.

Unsoundness refers to excessive volume change in the cement paste after setting. Any appreciable expansion, however slow, will result in cracking of the concrete. Unsoundness may be caused by the hydration of MgO or of free lime or by the reactions of C_3A with gypsum (sulfate expansion). Because these reactions are very slow, accelerated tests must be used to check for possible unsoundness.

The **heat of hydration** is defined as the amount of heat evolved during the setting and hardening of cement at a given temperature, measured in J/g of unhydrated cement.

Physical Properties of Mortars (Cement + Sand + Mortar)

Since the properties of mortars are also dependent on their consistencies, some specifications are written in terms of consistency. The consistency of mortars is expressed as mortar flow, defined in terms of the increase in diameter of a cone of mortar subjected to a specified jolting on a flow table.

Since mortar strength increases with curing time, the test age must be specified. Normally, minimum allowable strengths are specified for rapid hardening and low heat of hydration cements, respectively. Strengths are normally measured in either compression or flexure.

Compressive strength is by far the most common measure of strength required by cement specifications. It is normally measured at 3, 7 and 28 days.

Flexural strength is a measure of the tensile strength in bending, is particularly common in Europe, though its use is increasing in North America as well.

REFERENCES

REFERENCES

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2) Minerals Yearbook Centennial Edition 1981, Vol. I, Metals and Minerals; Bureau of Mines, U.S. Department of the Interior, p. 177.

3) Cement in Canada, D.H. Stonehouse; Mineral Resources Branch, Dept. of Energy, Mines and Resources, Canada 1973.

4) Canadian Minerals Yearbook, 1981; Department of Energy, Mines and Resources, Canada.

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GYPSUM

PROCTOR Plastex R PROCESS
MONTREAL QUEBEC

THE GYPSUM INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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DSS Contract Serial Number: OSQ82-00228

TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 3

  2.1 Operational Groups 2
  2.2 Products 2
  2.3 Raw Materials 3

3. PROCESS DESCRIPTION 4 - 13

  3.1 Gypsum Process Flow 4
  3.2 Gypsum Crushing 6
  3.3 Drying, Grinding and Calcining (Plant 325) 8
  3.4 Gypsum Board Plant 11

4. RESULTS AND DISCUSSION 14 - 22

  4.1 Gypsum Crushing 14

    4.11 Electrical Measurements 14
    4.12 Flowrates 15
    4.13 Size Distributions 15
    4.14 Grindability Testing 16
    4.15 Specific Energy Consumption 17

  4.2 Gypsum Drying, Grinding and Calcining 18

    4.21 Electrical Measurements 18
    4.22 Flowrates 19
    4.23 Size Distributions 19
    4.24 Specific Energy Consumption 20

5. CONCLUSIONS AND RECOMMENDATIONS 23

APPENDIX - Industry Review

  1. General Information
  2. Product Characteristics
  3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Caledonia, Ontario

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the gypsum industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 Operational Groups

Domtar Incorporated is a Canadian company with head office in Montreal. The company is organized into five operational groups including pulp and paper, construction materials, box and packaging, chemical products, and energy resource investments. Each operational group is further divided into various divisions, dealing in a particular area of interest. Divisions of the construction materials group include Canadian and U.S. gypsum operations, insulation products, masonry products and others.

Manufacture of gypsum products is in the hands of two divisions, one in Canada, the other in the U.S. Processing plants in the U.S. are located in California and Washington.

The Canadian gypsum products division has plants in British Columbia, Alberta, Manitoba, Ontario, Quebec, and Nova Scotia. Gypsum mining activities are located in Gypsumville, Manitoba, and Caledonia, Ontario.

2.2 Products

The plant at Caledonia manufactures two types of products: wallboard and plaster. Wallboard consists of re-hydrated gypsum set in a preformed shape. Plaster consists chiefly of ground, calcined gypsum containing some additives.

Additives to the gypsum during wallboard manufacture modify the setting rate as well as some properties of the finished product. The board is formed in 1.2 meter width and cut in various lengths to meet requirements. Of the two products manufactured at Caledonia, gypsum wallboard comprises the greater volume.

2.3 Raw Materials

The gypsum for the Caledonia plant occurs in a seam of about 4.6 meter thickness although the mined thickness varies from 2.1 to 2.7 meters.* It is fine-grained and white to light brown, interlayed with brown dolomite and, to some extent, with grey dolomite shale. A 30 cm shale layer above the roof of the mine is relatively impervious to water and serves to prevent excessive surface drainage into the mine.

The gypsum is mined using the room and pillar method, leaving about 20 percent of the gypsum in place for support and grade control. The rooms are of 6.1 to 6.7 meter width with 9.8 meter centers.

The ore is blasted, loaded and conveyed to the primary crushing system located in the mine. The mine has been in operation since 1952 and is accessed by an inclined 4.1 x 3.0 meter shaft. The seam is at a depth of 23 meters.

The ore contains about 72 percent gypsum with impurity being mainly dolomite. However, no beneficiation of the ore takes place in the process at Caledonia.

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* Gypsum in Ontario, G.R. Guillet; Ontario Dept. of Mines; Industrial Mineral Report No. 18 (1964).

3. PROCESS DESCRIPTION

3.1 Gypsum Process Flow

The process line at the Caledonia gypsum plant (Fig. I) uses a combination of equipment and processes that are common to many industries as well as some that are unique to the gypsum industry itself. Crushing, drying and grinding of the relatively soft ore is done with conventional equipment. However, the low temperature calcining technique applied at Caledonia is unique to the gypsum industry.* The technique of "sandwiching" calcined gypsum slurry between two layers of paper for rapid re-hydration and setting to form a gypsum "board" forms the background for the usefulness of gypsum in the construction industry.

The value of gypsum as a mineral rests chiefly in its ability to give up and re-gain associated water molecules in its crystal structure. The process is temperature dependant but high temperatures are not required. In its partially de-hydrated calcined form the gypsum is an easily handled powder. When mixed with water, the material re-gains water and "sets up" to form a fairly rigid mass, harder than the original ore.

The objective of the process is to calcine gypsum ore to form plaster or stucco, then re-hydrate in a slurry and allow it to harden after being formed into a board. This objective is accomplished at Caledonia in three stages. The ore is first processed through a primary crushing circuit. At the plant, the ore is dried of surface moisture,

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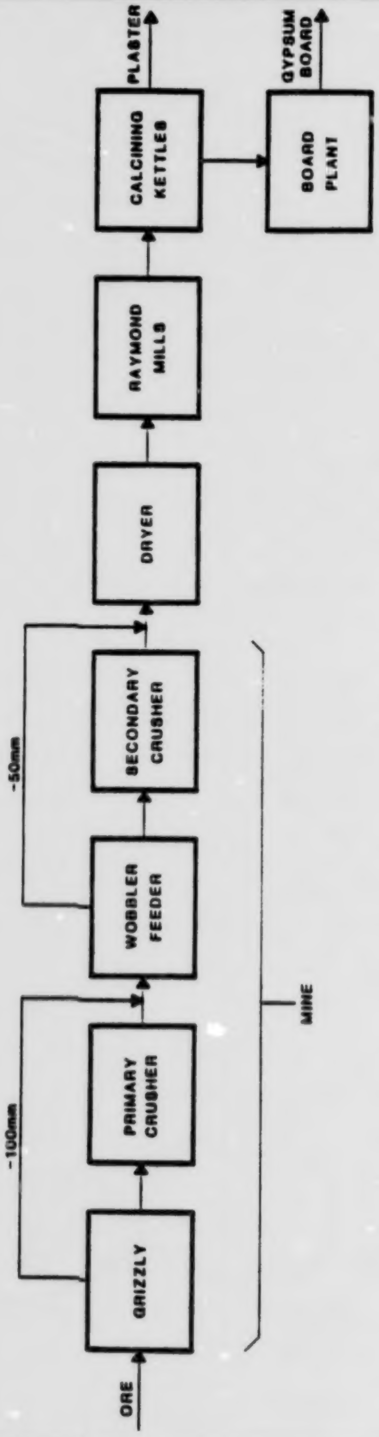
* The Canadian Gypsum Industry, R.K. Collings; Mineral Processing Div., Department of Mines and Technical Surveys, Ottawa (1959).

Figure I - PROCESS FLOW SHEET
DOMTAR GYPSUM DIVISION
CALEDONIA, ONTARIO

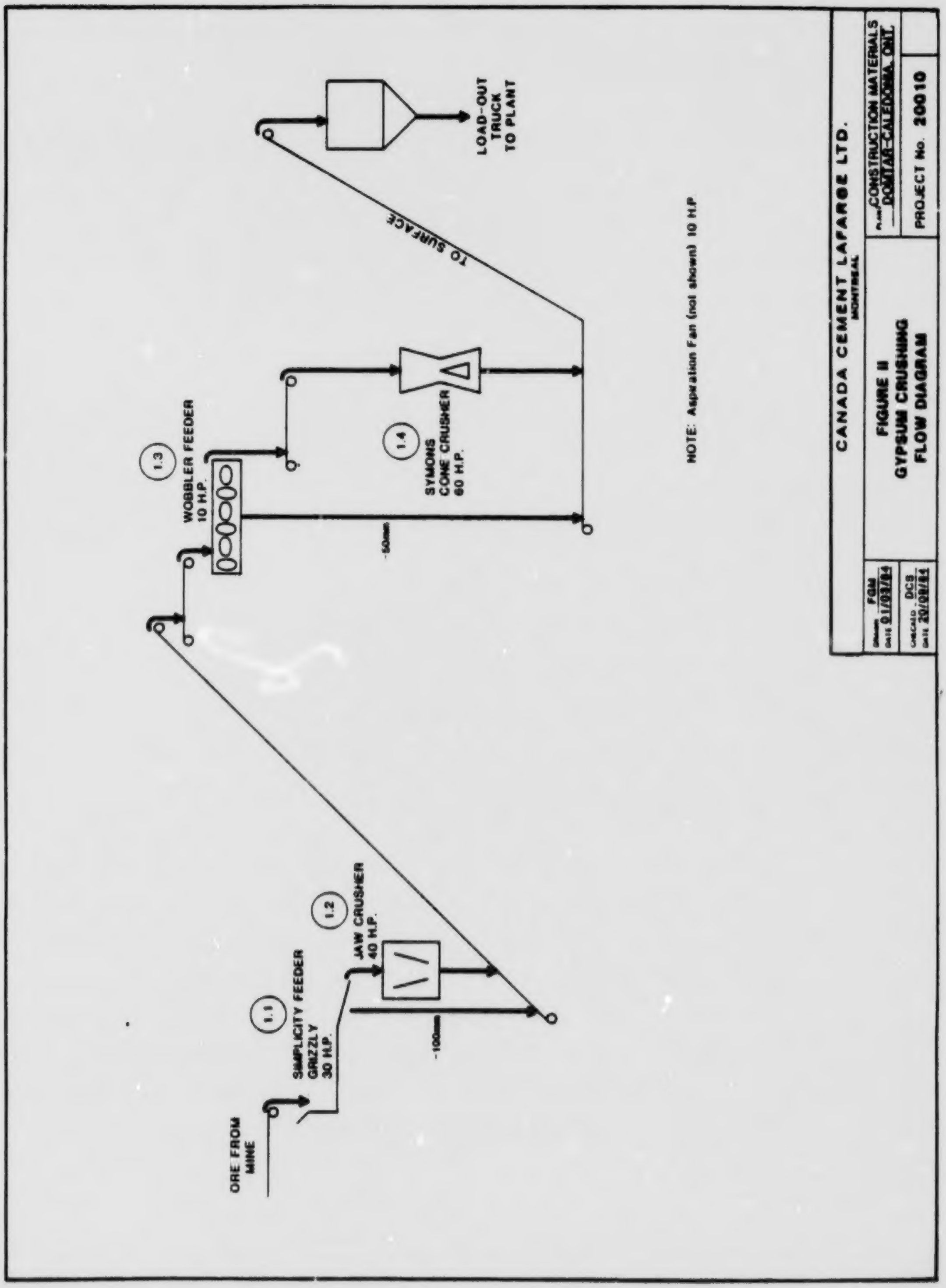

ORE
GRIZZLY
-100mm
PRIMARY CRUSHER
WOBBLER FEEDER
-50mm
SECONDARY CRUSHER
MINE
DRYER
RAYMOND MILLS
CALCINING KETTLES
PLASTER
BOARD PLANT
GYPSUM BOARD

ground and calcined. The final stage is the production of gypsum board in a continuous process. The product is then palletized for shipment.

3.2 Gypsum Crushing

Gypsum rock is transferred from the mine face by conveyor to the primary crushing circuit (Fig. II) which is located in the main conveyor way. The rock is held temporarily in a hopper which discharges to a vibrating grizzly feeder. The feeder, powered by a 30 HP motor, removes minus 10 cm material. The oversize material from the grizzly is fed to a 40 HP jaw crusher where it is reduced to a maximum size of 15 cm. The undersize from the grizzly and the primary crusher product is conveyed some distance along the conveyor way to the secondary crusher operation.

At the secondary crusher, the gypsum ore discharges from the belt conveyor to a Wobbler feeder. This device consists of a series of rotating shafts of roughly oval cross-section. The combined rolling and eccentric motion created by the feeder serves to move the material over the feeder while agitating it, allowing fine material to drop between the shafts. The Wobbler, which is powered by a 10 HP motor, removes minus 5 cm material from the ore. The oversize from the Wobbler feeder discharges to a belt feeding the material to a Symons cone crusher. The 60 HP secondary crusher reduces the material to 7.5 cm maximum size. The undersize from the Wobbler feeder and secondary crusher product discharge to a common belt conveyor which transfers the material to the surface through the inclined access tunnel. The gypsum is held in bins at the mine site from which it is loaded into trucks and hauled to the processing plants.


ORE FROM MINE
1.1
SIMPLICITY FEEDER GRIZZLY 30 H.P.
-100mm
1.2
JAW CRUSHER 40 H.P.
1.3
WOBBLER FEEDER 10 H.P.
-50mm
1.4
SYMONS CONE CRUSHER 60 H.P.
TO SURFACE
LOAD-OUT TRUCK TO PLANT
NOTE: Aspiration Fan (not shown) 10 H.P.
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE II
GYPSUM CRUSHING
FLOW DIAGRAM
PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.
PROJECT No. 20010
DRAWN FGM
DATE 01/09/84
CHECKED DCS
DATE 20/09/84

The entire crushing operation is relatively dust-free, requiring no dust collection equipment except for a 10 HP aspiration fan at the vibrating grizzly feeder to the jaw crusher.

The equipment list for the crushing circuit is presented in Table 1.

TABLE 1 - Gypsum Crushing Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Simplicity Feeder - Grizzly	30	32
1.2	Jaw Crusher	40	41
1.3	Wobbler Feeder	10	10
1.4	Symons Cone Crusher	60	66
1.5	Aspiration Fan	10	11

* All motors 550 volts

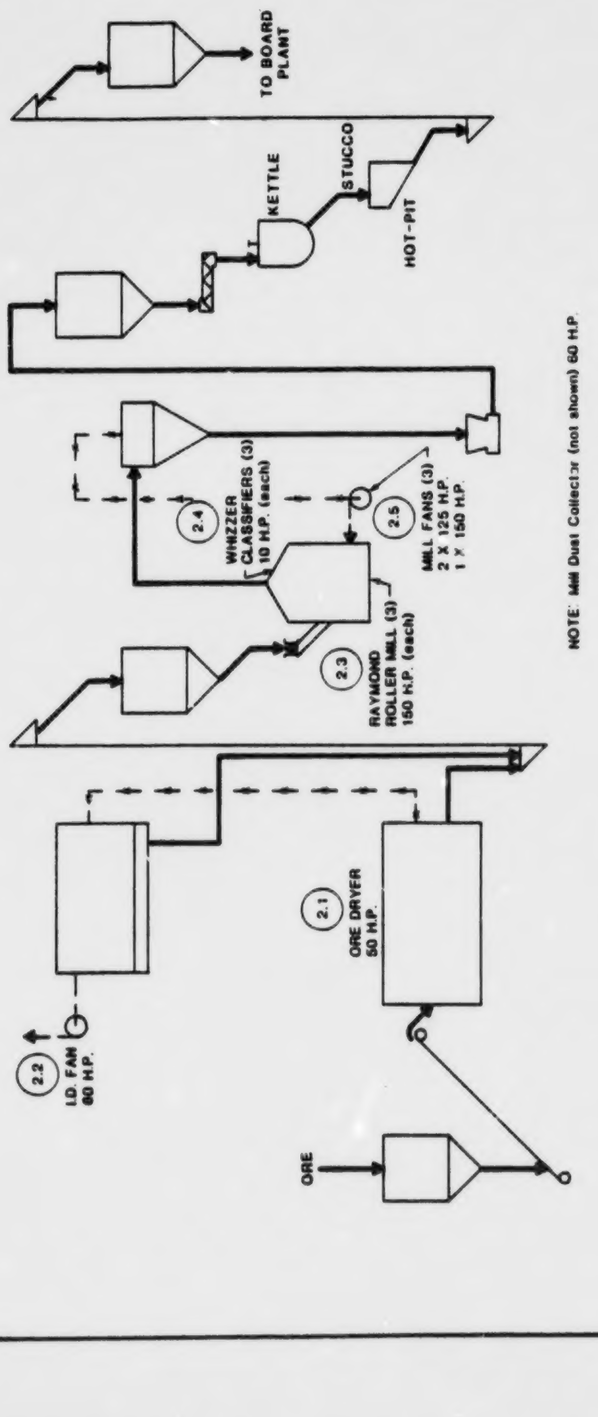
3.3 Drying, Grinding and Calcining (Plant 325)

Crushed ore is stored in a holding bin at the plant (Fig. III) then conveyed by belt to a rotary gas-fired dryer powered by a 50 HP motor. The material passes co-current with the hot gases. The dryer discharges through a screw conveyor and elevator to the feed bins for the Raymond mills. Draft through the dryer is provided by a 60 HP I.D. fan pulling air through a baghouse. The collected dust is returned to the dryer discharge.

Dried ore is metered by rotary feeders into 3 Raymond 6000 roller mills, each powered by a 150 HP motor. The material is carried from the grinding zone to a 10 HP variable speed whizzer classifier located in the upper part of the mill by draft from an external fan. Feed rate to the mills is by on-off control of the rotary feeder which regulates the pressure drop across the mill. The whizzer returns oversize material to the grinding zone. Product specification material is entrained out of the mill by draft to a cyclone which removes it from the airstream and sends it to a pump. Air from the cyclone is returned through the fan to the bottom of the mill. Two mills are equipped with 125 HP fans; the other has a 150 HP fan. Raymond mill product is ground to 95-97 percent passing 150 µm.

Calcination is a batch process involving 5 gas-fired kettles. Their capacities range from 9 to 18 tonnes. Each kettle is equipped with an internal agitator to mix the gypsum during calcining.

During a typical cycle, a kettle is filled with ground gypsum, the burner is fired and the material temperature raised to 160°C. The fire is shut off and the material rapidly dumped into a hot pit where it cools. The calcined material is then transferred by screw conveyor and elevator to a holding bin and thereafter to the board making plant.


ORE
2.2
I.D. FAN
60 H.P.
2.1
ORE DRYER
50 H.P.
2.3
RAYMOND
ROLLER MILL (3)
150 H.P. (each)
2.4
WHIZZER
CLASSIFIERS (3)
10 H.P. (each)
2.5
MILL FANS (3)
2 X 125 H.P.
1 X 150 H.P.
KETTLE
STUCCO
HOT-PIT
TO BOARD
PLANT

NOTE: Mill Dust Collector (not shown) 60 H.P.

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE III
GYPSUM GRINDING + CALCINING
FLOW DIAGRAM

PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.

PROJECT No. 20010

DRAWN FGM
DATE 02/03/84

CHECKED DCS
DATE 20/09/84

The equipment list for drying and grinding is presented in Table 2.

TABLE 2 - Grinding and Calcining Equipment List

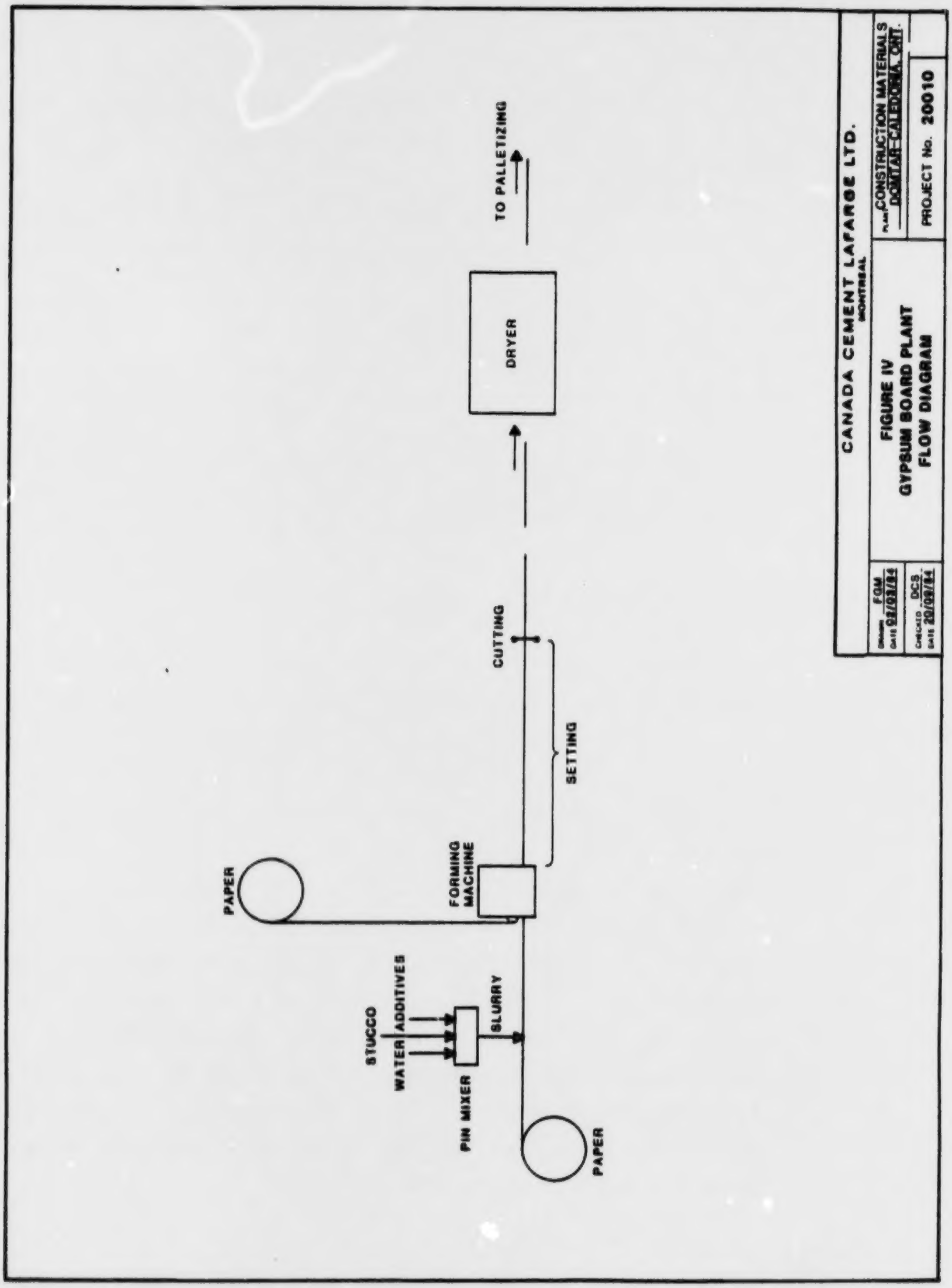
EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
2.1	Ore Dryer (Gas)	50	48
2.2	Dryer I.D. Fan	60	57
2.3	Raymond Roller Mill 6000 (3)	150	140
2.4	Whizzer Classifier (3)	10	11
2.5	Mill Fan (2)	125	116
	(1)	150	145
2.6	Mill Dust Collector	60	57

* All motors 550 volts

3.4 Gypsum Board Plant

The board plant (Fig. IV) is made up of a number of steps including forming, setting, cutting, drying, and palletizing, all integrated into one continuous production line.

Two rolls feed paper simultaneously, a layer for each side of the board. Stucco, along with controlled proportions of water and additives, are metered into a pin mixer where a uniform slurry is produced. This mixture is sandwiched between the two layers of paper and fed into a board-forming unit, which consists of two forming rolls and auxiliary equipment for turning and gluing the edges of the paper. The board leaves the machine with well-defined surfaces and edges. The temperature of the stucco is closely controlled to optimize the setting time of the gypsum when mixed with water.


STUCCO
WATER
ADDITIVES
PIN MIXER
SLURRY
PAPER
PAPER
FORMING MACHINE
SETTING
CUTTING
DRYER
TO PALLETIZING
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IV
GYPSUM BOARD PLANT
FLOW DIAGRAM
PLANT CONSTRUCTION MATERIALS
DOMTAR-CALEDONIA, ONT.
PROJECT No. 20010
DRAWN FGM
DATE 02/03/84
CHECKED DCS
DATE 20/03/84

The board from the forming unit is maintained in a continuous length, supported and carried along by a roller conveyor system. During this time setting of the gypsum layer occurs. The board is then cut by rotary cutters to lengths varying from 1.8 to 3.6 meters. Despite the fact that some water is required in the gypsum crystal structure for setting, sufficient excess water is added to the stucco to require drying. This is accomplished by the use of a gas fired, multi-deck unit. The boards take more than half an hour to pass through the dryer in which the temperature ranges from 170°C at the inlet to 90°C at the discharge end. The boards are then stacked and palletized for storage and shipment.

The process is monitored continuously at key points and, should defects in board or paper occur, corrections are made immediately to ensure a quality product.

4. RESULTS AND DISCUSSION

4.1 Gypsum Crushing

4.11 Electrical Measurements

Measured power demand of comminution and auxiliary equipment in the primary crushing circuit (Table 3) were calculated from measured volts, amp and power factor readings. Comparison of measured power levels with rated horsepower shows that the circuit is operating well under capacity.

An exception is the aspiration fan drive at the feeder-grizzly which was operating well above its rated power. This motor operates a small un-dampered fan drawing dust from the area around the feeder and venting it into an abandoned area of the mine. There is no dust collection device associated with it.

TABLE 3 - Primary Crushing Measurements

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
1.1	Simplicity Feeder	30	8.5	8.5	8.5
1.2	Jaw Crusher	40	10.1	10.1	10.1
1.3	Wobbler Feeder	10	2.1	2.1	2.1
1.4	Cone Crusher	60	29.7	29.7	29.7
1.5	Aspiration Fan	10	10.4	10.4	10.4

Electrical measurements in the primary circuit were taken during a period of steady operation at peak throughput.

4.12 Flowrates

Personnel at the mine indicated that the mine produces, on average, about 2350 tonnes of crushed gypsum ore per day in two eight-hour shifts. However, to calculate specific power consumption for the circuit from the electrical measurements, it was desirable to use the instantaneous or peak flowrate at the time the measurements were made. This was estimated from the final product belt. Using a belt speed of 91.5 m/min, a material bed width of 30.5 cm and average depth of 9 cm, and a crushed gypsum bulk density of 1370 kg/m^3, a flowrate of 210 t/h was established and used to calculate energy consumption. A production of 2350 tonnes in 16 hours implies a utilization factor of about 70%. This allows for start-up time, which is significant, and down time for repairs and shift changes.

Flowrates through individual crushers were also estimated. About two-thirds of the incoming circuit feed bypassed the jaw crusher giving a flowrate through the crusher of 70 t/h. The split at the Wobbler feeder before the cone crusher was about 50:50 giving a cone crusher flowrate of 105 t/h.

4.13 Size Distributions

Most size distribution data pertaining to the crushing circuit is given in Table 4. The feed material to the circuit was observed to have a maximum size of about 300 mm with most of the material being -150 mm. The primary crusher product, a mixture of jaw crusher discharge and grizzly undersize, has been reduced to 150 mm, with a significant proportion of -50 mm.

TABLE 4 - Domtar Gypsum Crushing Circuit Size Distributions (% Passing)

mm	CIRCUIT FEED[1]	PRIMARY CRUSHER PRODUCT[1]	SECONDARY CRUSHER FEED[1]	CIRCUIT PRODUCT[2]
300	100			
150	80	100	100	
100		85	93	
75			80	100
50	40	60	20	90
38				80
25				60
19				50
12.5				40
4.75				20

[1] Estimated
[2] Sieve Analysis

The secondary or cone crusher feed, the Wobbler feeder oversize, has most of the -50 mm material removed. The circuit product, a mixture of cone crusher discharge and Wobbler feeder undersize, has been reduced to -75 mm with most of the material smaller than 50 mm. The circuit product size data was obtained by sieve analysis. A more detailed distribution is given in 4.2 as Raymond mill feed.

4.14 Grindability Testing

An attempt was made to determine the Bond Work Index on a sample of crushed gypsum ore from the Caledonia mine. However, it was found that the material tended to coat the grinding media and impede the flow of material from the test mill. Therefore the Bond Work Index could not be determined. The Hardgrove Index was found to be 61. The Bond Index of 10.32 kWh/Ton was calculated from the Hardgrove result. The calculated Bond Index appears to be high for gypsum. However, the Caledonia ore contains significant impurities which may influence the test results.

4.15 Specific Energy Consumption

Energy consumption data for the primary crushing circuit (Table 5) shows the total specific energy of the circuit to be low with comminution energy making up 2/3 of the total.

Since primary processing of mineral ores generally involves drying of surface moisture, the specific energy for drying itself was calculated (Table 6) from the measurements of dryer and I.D. fan drives (Table 8). The flowrate through the dryer was taken to be the same as the combined production rate of the Raymond mills (41 t/h).

The drying energy consumption was added to the primary circuit specific energy to arrive at the consumption for dry ore preparation (Table 7).

The comminution consumption accounts for just over 1/10 of the cumulative specific energy to this point.

The low energy consumption of the primary circuit itself reflects the degree to which the material is reduced in size, and the relative ease with which it is crushed.

TABLE 5 - Primary Crushing - Specific Power Consumption

	kWh/tonne	%
Comminution	0.19	66
Auxiliaries	0.10	34
Total	0.29	100

TABLE 6 - Drying - Specific Power Consumption

	kWh/tonne
Consumption	1.17

TABLE 7 - Dry Ore Preparation
Specific Power Consumption

	kWh/tonne	%
Comminution	0.19	13
Auxiliaries	1.27	87
Total	1.46	100

4.2 Gypsum Drying, Grinding and Calcining

4.21 Electrical Measurements

Measured power levels in the gypsum drying and grinding circuit (Table 8) reveal both dryer drive and I.D. fan motors to be operating at about 60% of their rated power under steady load.

TABLE 8 - Drying and Grinding Measurements

			POWER OBSERVATIONS - kW		
No.	EQUIPMENT	MOTOR HP	MAX.	MIN.	AVG.
2.1	Dryer	50	21.7	21.7	21.7
2.2	I.D. Fan	60	26.3	26.3	26.3
2.3	Raymond Mill #1	150	135	135	135
	#2	150	118	118	118
	#3	150	115	115	115
2.4	Whizzer #1	10	3.7	3.7	3.7
	#2	10	3.3	3.3	3.3
	#3	10	4.5	4.5	4.5
2.5	Fan #1	125	95.2	95.2	95.2
	#2	150	96.3	96.3	96.3
	#3	125	103	103	103
2.6	Dust Collector	60	17.6	17.6	17.6

The Raymond mill motors were found to be operating steady at near full rated amps. Combined with a relatively high observed power factor (0.9), all three mill motors were at or exceeding their rated power output. Similarly the fan motors were observed to have high power factors and were operating at 85-90% of their rated capacity.

The whizzer classifier drives were observed to be operating at about half their capacity. The single dust collector fan for the Raymond mill circuit was operating at under half its capacity. All motors in the drying and grinding circuit were operating with little or no fluctuation in power.

4.22 Flowrates

The production rate of the circuit obtained from plant records was 41 t/h.

4.23 Size Distributions

Particle size analyses pertaining to mill circuits (Table 9) were determined for feed and product. The feed stream corresponds to the final product from the primary crushing circuit. This material is generally referred to in the plant as being -50 mm.

The product from the mill circuit, prior to calcining, has been reduced to -425 μm. The in-plant target for the Raymond mill product is 95-97% passing 150 μm.

Particle size analysis revealed that this material was slightly below the target. An interesting point concerning the data on the mill product is the large proportion of superfine material. Nearly half the sample was -10 µm. It is apparent that a significant amount of over-grinding is taking place in the Raymond mills.

TABLE 9 - Domtar Raymond Mill Circuit Size Distributions (% Passing)

SIZE	FEED	PRODUCT
75 mm	100	
50	90.5	
25	61.9	
12.5	40.0	
4.75	22.4	
1.18	11.4	
425 µm		100
300	5.7	98.8
150	3.8	93.0
106		84.5
75		78.3
45		75.5
30		69.5
20		63.0
10		48.0
6		35.0
2		13.5

Due to the design of the Raymond mill, oversize material from the whizzer classifier is returned to the grinding zone in an internal stream. Therefore, this recirculating material could not be sampled to determine the particle size distribution or obtain further information on the whizzer performance or magnitude of the circulating load.

4.24 Specific Energy Consumption

The total specific consumption for the Raymond mill circuit (Table 10) is relatively low at 17 kWh/t. Comminution consumption accounts for just over half of the total energy. This is a typical result for a Raymond mill since the mill and fan motors are rated about equally. The slightly greater comminution energy is accounted for by the heavier loading of the mill motors compared to the fan and whizzer drives.

TABLE 10 - Gypsum Grinding
Specific Power Consumption

	kWh/tonne	%
Comminution	8.98	53
Auxiliaries	7.92	47
Total	16.9	100

Cumulative energy consumption for gypsum crushing and grinding (Table 11) is shown for stucco. The reported consumption allows for a yield of 89% at the calcining step since most of the chemically associated water in the gypsum is driven off. The comminution consumption has decreased to exactly half of the total as a result of the low proportion of specific energy in the primary circuit made up by comminution alone.

TABLE 11 - Stucco
Cumulative Power Consumption

	kWh/tonne	%
Comminution	10.3	50
Auxiliaries	10.3	50
Total	20.6	100

Specific energy consumption for comminution and auxiliaries for finished gypsum board was not expressed as consumption per unit weight since board is generally measured in terms of surface area. The total thermal consumption for gypsum board production is of the order of 3.4 GJ/100 m^2. The specific electrical energy consumption for crushing and grinding was converted to equivalent thermal energy for thermal generation (1 kWh from 10.5 MJ) and expressed as a percentage of total thermal consumption (Table 12). Since the stucco is re-hydrated to make board, the calcining yield factor is removed from the calculation. The results show that, even in terms of equivalent thermal energy, crushing and grinding consumption is about 2.5% of the total energy required. Most of the energy is needed for drying the board after forming.

TABLE 12 - Gypsum Board
Cumulative Power Consumption

(% of total equivalent thermal energy)

	%
Comminution	2.5
Comminution & Auxiliaries	5.0

5. CONCLUSIONS AND RECOMMENDATIONS

Specific electric energy consumption for crushing and grinding of gypsum at Caledonia is relatively low, relating to other industrial minerals in general and in relation to the total equivalent thermal energy required per unit of finished gypsum board. The low consumption is attributed to the grindability of gypsum and the fact that fine grinding is not required.

The power consumption of the primary crushing circuit shows this part of the process to be operating quite efficiently during peak throughput with the average consumption probably being somewhat higher as a result of start-up time and interrupted production. The electrical measurements indicated that the crushers, particularly the jaw crusher, had some spare productive capacity which might be used by feeding a coarser material to the circuit and maximizing the utilization factor of the circuit.

The total energy for dry ore preparation is comparable to that of other minerals and is relatively low; about 1.5 kWh/t. Although the crushed ore is referred to as being -50 mm, some larger material was observed at between 50 and 75 mm.

The Raymond mill product was found to fall slightly below the target of 95% passing 150 µm. However, the amount of -10 um material in the ground product was significant. The superfine material may be evidence of over-grinding possibly due to a high circulating load inside the Raymond mills.

Overall, power consumption in crushing and grinding is small. Any improvement in specific energy would be expected to have minimal effect on the overall manufacturing cost.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

The term "gypsum" is used as a commercial and generic term for all calcium sulfate materials. Gypsum is a hydrated calcium sulfate ($CaSO_4$, $2H_2O$) commonly found in close association with anhydrite which is the anhydrous calcium sulfate ($CaSO_4$). These minerals generally occur as sedimentary rocks associated with limestone, shale or clay. Most gypsum is white to grayish white, but impurities can change the colour of the rock and final products.

Gypsum was used by the Egyptians and by the Romans as a plaster for important buildings and remains, to this day, a major material for the building industry, mainly in prefabricated products. It is produced in 62 countries around the world. The largest producer is the U.S.A. which accounted for about 15% of the world production in 1981. It is followed by Canada with about 10% of the world production. The other main producers are: France, U.S.S.R., Spain, United Kingdom, West Germany, China, Mexico, and Italy. Typical gypsum production volumes are shown in Table 1.

TABLE 1 - Gypsum - USA, Canada, World Production 1978-82[1]

(in thousands of tonnes)

	1978	1979	1980	1981	1982*
U.S.A.	13,509	13,200	11,227	10,430	10,160
Canada	8,074	8,098	7,336	7,800	7,530
World	70,276	74,400	71,500	77,094	74,389

* estimated

In 1978, the world reserves were estimated at about two billion tonnes; 350 million tonnes in the United States, 410 million tonnes in Canada and 900 million tonnes in Europe.

Gypsum is mined from open pit and underground mines. Most crude gypsum is used as mined, but it is possible to beneficiate some low grade ores.

Processing of crude gypsum depends on the end use. Gypsum for cement is crushed to minus 38 mm, plus 9.5 mm and gypsum for agricultural or filler use is pulverized to 150 µm or finer. For the other uses, the first stage is primary crushing using jaw or gyratory crushers to reduce the ore to about 150 mm. Then ore is shipped to processing plants where it is reduced to about 50 mm by roll crushers or hammer mills. Ground ore is dried in rotary driers and then reduced to about 150 µm by hammer mills and roller mills. The next step is calcination, usually in large batch kettles. Modern plants tend to grind and calcine in a single stage.

Calcination can also be done prior to grinding. In that case, plants use rotary kilns where coarse feed is continuously calcined. Then the calcined gypsum is ground to about 150 µm in roller, ball, or tube mills.

Calcination is a very important step which aims to release three quarters of the chemically combined water of gypsum ($CaSO_4$, $2H_2O$) to obtain the hemihydrate ($CaSO_4$, $\frac{1}{2}H_2O$). Calcined gypsum ("stucco") mixed with water is commonly called "plaster of Paris".

The calcined gypsum is manufactured in a plaster plant or in a board plant. Plaster plants use tube mills where calcined gypsum is reground to get a flake-like grain. Different additives such as accelerators or retarders and other ingredients are mixed with the stucco to meet consumers requirements.

In board plants additives including "land plaster" (ground gypsum) are mixed with the stuçco to form a slurry which is conveyed through two rolls of absorbent paper, cut and dried to be manufactured into wallboards and laths.

A special high temperature treatment in rotary kilns converts crushed gypsum to insoluble anhydrite. This product is manufactured into a harder and stronger plaster called Keene's cement.

By-product gypsum, which is a chemical product obtained from industrial processes such as acidulation of phosphate rock, hydrofluoric acid, citric acid and desulfurization of stack gas in thermal power plants, accounts for 25% of world gypsum consumption. No by-product gypsum is used in Canada.

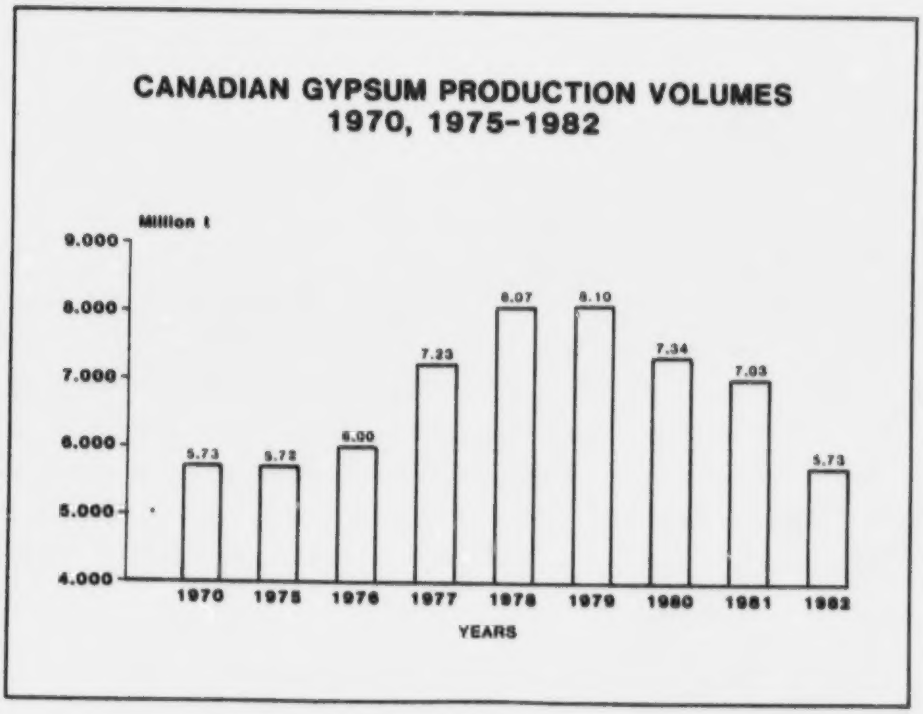
The Canadian Industry

The first production of gypsum in Canada was recorded in Nova Scotia in about 1760. The principal gypsum producing province is Nova Scotia which contributed about 75% of the Canadian production in 1982. The other main sources are located in British Columbia, Ontario, Newfoundland, and Manitoba. A breakdown of the production by province in 1981 and 1982 is shown in Table 2.

TABLE 2 - Gypsum Production - Breakdown by Province 1981-82[2]

	1981		1982	
	'000 t	$ Million	'000 t	$ Million
Nova Scotia	4,993	29.45	4,290	27.7
British Columbia	685	5.8	415	5.5
Ontario	613	5.2	506	4.5
Newfoundland	512	3.8	416	3.3
Manitoba	202	2.4	88	1.5
New Brunswick	20	87,000 $	10	52,000 $
TOTAL	7,025	46.8	5,726	42.6

In 1980, about 67% of Canadian production was exported to the United States as crude gypsum. The remainder was used domestically. Canadian production volumes in 1970 and from 1975 to 1982 are shown in the diagram below.



Source: Canadian Minerals Yearbook 1982, EMR Canada.

Gypsum mining and gypsum products operations in 1981 are shown in Tables 3 and 4.

TABLE 3 - Canada, Summary of Gypsum Mining Operations, 1982[1]

PROVINCE - COMPANY	LOCATION	REMARKS
Newfoundland		
Flintkote Holdings Ltd.	Flat Bay	Open-pit mining of gypsum
Nova Scotia		
Little Narrows Gypsum Co.	Little Narrows	Open-pit mining of gypsum & anhydrite
Georgia-Pacific Corp.: Bestwall Gypsum Div.	River Denys	Open-pit mining of gypsum
Fundy Gypsum Co. Ltd.	Wentworth & Miller Creek	Open-pit mining of gypsum & anhydrite
National Gypsum (Canada)	Milford	Open-pit mining of gypsum
Domtar Inc.	MacKay Settlement	Open-pit mining of gypsum
New Brunswick		
Canada Cement Lafarge Ltd.	Havelock	Open-pit mining of gypsum used in cement manufacturing
Ontario		
Canadian Gypsum Co. Ltd.	Hagersville	Underground mining of gypsum
Domtar Inc.	Caledonia	Underground mining of gypsum
Westroc Industries Ltd.	Drumbo	Underground mining of gypsum
Manitoba		
Domtar Inc.	Gypsumville	Open-pit mining of gypsum
Westroc Industries Ltd.	Amaranth	Open-pit mining of gypsum
British Columbia		
Western Gypsum Ltd.	Windemere	Open-pit mining of gypsum
Canada Cement Lafarge Ltd.	Falkland	Open-pit mining of gypsum

Source: Energy, Mines, and Resources Canada

TABLE 4 - Canada, Summary of Gypsum Products Operations, 1982[1]

PROVINCE - COMPANY	LOCATION	REMARKS
Newfoundland		
Atlantic Gypsum Ltd.	Corner Brook	Gypsum products manuf.
Nova Scotia		
Domtar Inc.	Windsor	Gypsum plaster manuf.
Quebec		
Canadian Gypsum Co Ltd	Montreal	Gypsum products manuf.
Canadian Gypsum Co Ltd	St-Jérôme	Gypsum products manuf.
Domtar Inc.	Montréal	Gypsum products manuf.
Westroc Industries Ltd	Ste-Catherine d'alexandrie	Gypsum products manuf.
Ontario		
Canadian Gypsum Co Ltd	Hagersville	Gypsum products manuf.
Domtar Inc.	Caledonia	Gypsum products manuf.
Westroc Industries Ltd	Clarkson	Gypsum products manuf.
Manitoba		
Domtar Inc.	Winnipeg	Gypsum products manuf.
Westroc Industries Ltd	Winnipeg	Gypsum products manuf.
Saskatchewan		
Genstar Corporation	Saskatoon	Gypsum products manuf.
Alberta		
Domtar Inc.	Calgary	Gypsum products manuf.
Westroc Industries Ltd	Calgary	Gypsum products manuf.
Genstar Corporation	Edmonton	Gypsum products manuf.
British Columbia		
Westroc Industries Ltd	Vancouver	Gypsum products manuf.
Domtar Inc.	Vancouver	Gypsum products manuf.
Genstar Corporation	Vancouver	Gypsum products manuf.

Source: Energy, Mines, and Resources Canada

Market Outlook

Gypsum is abundant throughout the world but is used mainly in industrialized countries. Crude gypsum is a low cost commodity and the consumer's cost is closely dependent on transportation costs. This explains why some plants are operated by U.S. companies which find it more cost effective to import gypsum from Canada rather than mining U.S. deposits. In the same way, Canadian provinces such as Ontario, Alberta, and British Columbia used to import wallboard from U.S.A., but these imports have greatly declined during the last few years.

In 1982, U.S. demand was weak and Canadian gypsum production was down 20% from 1981. Such a drop can be explained by a slump in the construction industry in North America.

In the long run, consumption of prefabricated gypsum products is expected to increase steadily while building and industrial plasters should decline. While an increased utilization of fertilizer could result in a greater use of gypsum as a soil conditioner in future, the major developments should occur in the area of building materials despite competition from other materials substitution, such as plywood and particle boards, cement, concrete, and steel.

Most of the commercial gypsum is 85% to 95% pure as produced. The main impurities are limestone, shale, or clay. The amount of impurities which can be tolerated depends upon the type of impurity, the final product and the competitive situation. The chemical analyses of pure gypsum and anhydrite are shown in Table 5.

TABLE 5 - Chemical Analysis of Pure Gypsum - Anhydrite[3]

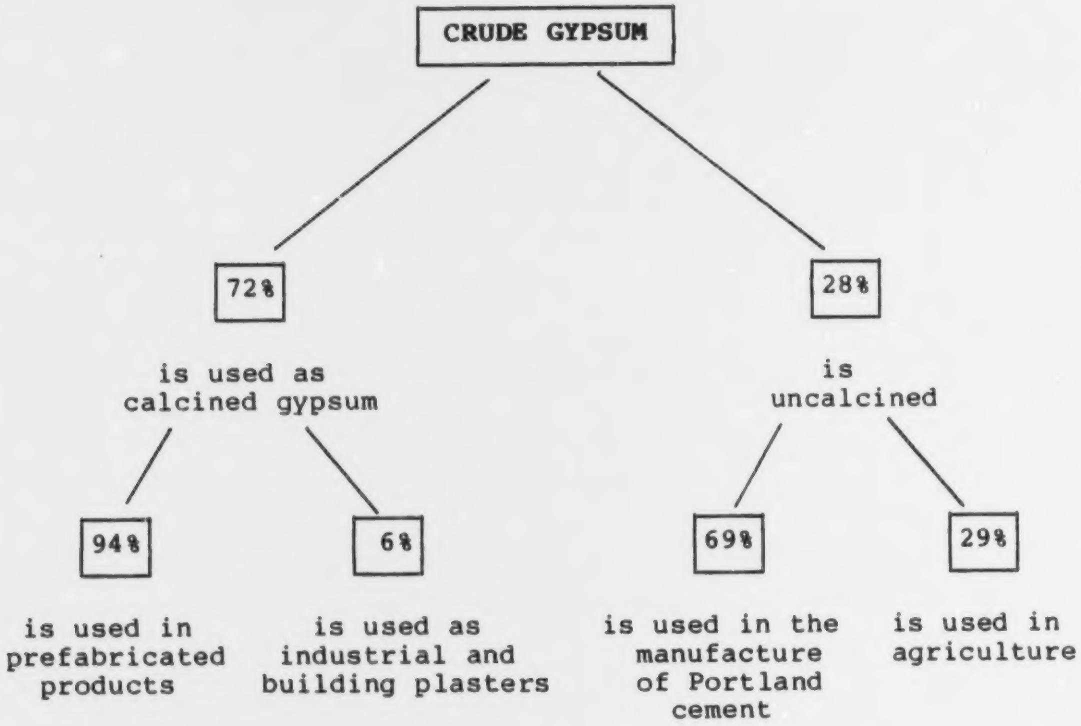
	Pure Gypsum	Anhydrite
Combined water	20,9%	-
Sulfur trioxide (SO_3)	46,6%	58,8%
Lime (CaO)	32,5%	41,2%

Gypsum is slightly soluble in water, soluble in dilute hydrochloric acid and insoluble in sulfuric acid. Uses of crude gypsum, also called "land plaster", are listed below:

- Manufacture of Portland cement. Gypsum acts as a retarder to control the setting of concrete.
- Filler in paint or paper manufacture.
- Substitute for salt cake in glass manufacture.
- Soil conditioner.

The breakdown by uses in U.S.A. in 1981 was as follows:

FIGURE 2 - Gypsum - Breakdown by Uses - U.S.A. 1981


CRUDE GYPSUM
72%
is used as calcined gypsum
28%
is uncalcined
94%
is used in prefabricated products
6%
is used as industrial and building plasters
69%
is used in the manufacture of Portland cement
29%
is used in agriculture

The tests to monitor quality, according to the different products, are listed in Table 6.

TABLE 6 - Gypsum Products - Tests to Monitor Quality

PRODUCT	TESTS
• Gypsum	• Chemical Analysis • Fineness
• Gypsum Plasters (incl. Keene's Cement)	• Chemical Composition • Fineness • Time of setting • Compressive Strength
• Lath, Wallboard, Sheeting	• Composition • Flexural Strength • Size-Weight-Finish
• Gypsum Tile or Block	• Composition • Compressive Strength • Dimensions

REFERENCES

REFERENCES

1. Canadian Minerals Yearbook 1976, 1979, 1981, Energy, Mines and Resources, Canada.

2. Canadian Mining Journal, Vol. 104, February 1983.

3. Industrial Minerals and Rocks, A.I.M.E., 4th Edition, 1975, S.J. Lefond, Editor.

4. Canadian Gypsum Industry, Department of Mines and Technical Surveys, Ottawa, 1959.

LINE

THE LIME INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 5

  2.1 General 2
  2.2 The Lime Division 2
  2.3 Products Marketed 3

3. PROCESS DESCRIPTION 6 - 16

  3.1 Lime Process Flow 6
  3.2 Limestone Crushing and Classification 8
  3.3 Lime Crushing and Screening 11
  3.4 Hydrated Lime Plant 15

4. RESULTS AND DISCUSSION 17 - 28

  4.1 Limestone Crushing and Screening 17

    4.11 Electrical Measurements 17
    4.12 Flowrates 18
    4.13 Size Distribution 20
    4.14 Grindability Testing 22
    4.15 Specific Energy Consumption 22

  4.2 Lime Processing 24

    4.21 Electrical Measurements 24
    4.22 Flowrates 26
    4.23 Size Distribution 26
    4.24 Grindability Testing 27
    4.25 Specific Energy Consumption 27

5. CONCLUSIONS AND RECOMMENDATIONS 29

APPENDIX - Industry Review

  1. General Information
  2. Product Characteristics
  3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Joliette, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the lime industry studied, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

Domtar Inc. was approached as a representative lime producer whose comminution operations could be monitored. The lime plant located at Joliette, Quebec was selected to conduct the data collection campaign.

2.1 General

Domtar Inc. is one of the largest Canadian industrial groups operating over 70 manufacturing plants distributed in Canada and the United States of America. The total sales of the company were close to $1.7 billion in 1982.

The large number of activities and products sold by this company are divided among five operating groups which can be listed in decreasing importance as follows:

1 - Pulp and Paper : 50% of sales
2 - Construction Materials : 19% of sales
3 - Box and Packaging : 15% of sales
4 - Chemical Products : 16% of sales
5 - Energy Resources Investments

2.2 The Lime Division

Domtar's Lime Division is the largest lime producer in Canada. In 1982, with sales of $29 million, it accounted for about 20% of total sales in Canada. In terms of production volume, the capacity of Domtar is estimated at 600,000 tonnes per year representing about 18% of Canadian capacity.

The production capacity is from two plants, one in Ontario and one in Quebec.

The plant located at Joliette, Quebec, has a capacity of 300,000 tonnes per year and produces quicklime and hydrated lime as well as a variety of limestone products essentially for construction and agricultural uses.

The Joliette plant consists of three rotary kilns, built at different times in the sixties and the seventies. Two kilns are of a conventional type, and one is a grate-kiln system (Allis Chalmers-Lepol).

During the survey period (April 1983), only kiln #3 which has an annual capacity of 150,000 tonnes was operating.

2.3 Products Marketed

Typical specifications of the plant's products are listed in Tables 1 and 2.

Almost half of the lime production is sold to the steel industry where it is used as a flux. The main requirements of this market are a low sulfur content and the absence of fines. The lime is thus a typical pebble material having a size gradation specification of minus 50 mm and plus 4.75 mm. It is made by feeding the kiln with a limestone having a coarse and narrow size gradation (12.5 x 50.0 mm) and by screening twice, the minus 6.3 mm fraction, first after cooling and before storage, secondly before loading into a truck for shipping. The sulphur specification is set at 0.08% maximum.

TABLE 1 - Domtar - Joliette Lime Plant Products Marketed

LIME PRODUCT	SIZE GRADATION	CHEMICAL CRITERIA
1) Hi-Calcium Quicklime (Steel Making)	100% minus 50.0 mm	% S=0.08 max.
2) Hi-Calcium Quicklime	100% minus 19.0 mm 8% minus 4.75 mm	% S=0.2 or 0.08 max.
3) Hi-Calcium Quicklime	100% minus 6.7 mm 80% minus 2.36 mm 45% minus 600 µm	% S=0.1
4) Hi-Calcium Pulverized Quicklime (-3.35 mm)	100% minus 4.75 mm 98% minus 3.35 mm 85% minus 1.18 mm 70% minus 600 µm	% S=0.1
5) Hi-Calcium Hydrated Lime	96% minus 300 µm 92% minus 150 µm 86% minus 75 µm 80% minus 45 µm	Nil

TABLE 2 - Domtar - Joliette Lime Plant Products Marketed - Limestone Products

1) Aggregate Stone

% Passing	6.3 x 12.5 mm	12.5 x 19.0 mm	19.0 x 31.5 mm	31.5 x 50.0 mm
50.0 mm				100
38.1 mm			100	61
25.0 mm		100	68	3
19.0 mm	100	86	14	1
12.5 mm	99	18	2	
9.5 mm	56	3		
4.75 mm	3			

2) Chemical Stone (0 x 6.3 mm)	- 96% $CaCO_3$	100% minus 6.7 mm 72% minus 3.35 mm 40% minus 1.00 mm 16% minus 150 µm
3) Agricultural Limestone	- 92% $CaCO_3$	100% minus 3.35 mm 80% minus 850 µm 41% minus 150 µm
4) Pulverized Limestone		99% minus 150 µm 85% minus 75 µm 70% minus 45 µm

The second major market for the Joliette plant is in non-ferrous metallurgical uses, particularly in the aluminum industry for production of alumina from bauxite and in the copper and zinc industries.

The third important market is in pulp and paper where lime plays a major role as a causticizing agent in the sulfate process. It is also used in this industry for other purposes, such as the preparation of bleaching liquors, a dissolver and a neutralizing agent.

Fourthly, the water treatment sector represents an important and growing market. Here, lime is used chiefly for softening, purification and neutralization.

For these markets (non-ferrous metals, pulp and paper, water treatment), higher fineness will generally be an advantage as the solution rate is thus increased. The hydrated lime is often used in the water treatment sector by smaller users that cannot justify the investment for a slaker and the expense of another processing step required when using quicklime.

The limestone products contribute significantly to the sales of the Joliette lime plant. Except for the pulverized limestone (minus 150 μm) which is mainly used as a filler material in the manufacture of roof shingles, the other products, aggregate stone and agricultural stone, are very seasonal. Nevertheless, the sales of aggregate stone can exceed 500,000 tonnes.

3. PROCESS DESCRIPTION

3.1 Lime Process Flow

A general process flow sheet for lime manufacture is illustrated in Figure I. Lime manufacture can be simplified to three basic steps:

- stone preparation (kiln feed),

- calcination,

- lime hydration.

The stone preparation comprises selective mining, primary crushing, stone classification by screening, and secondary crushing of the oversize (plus 50 mm) in closed circuit with screening.

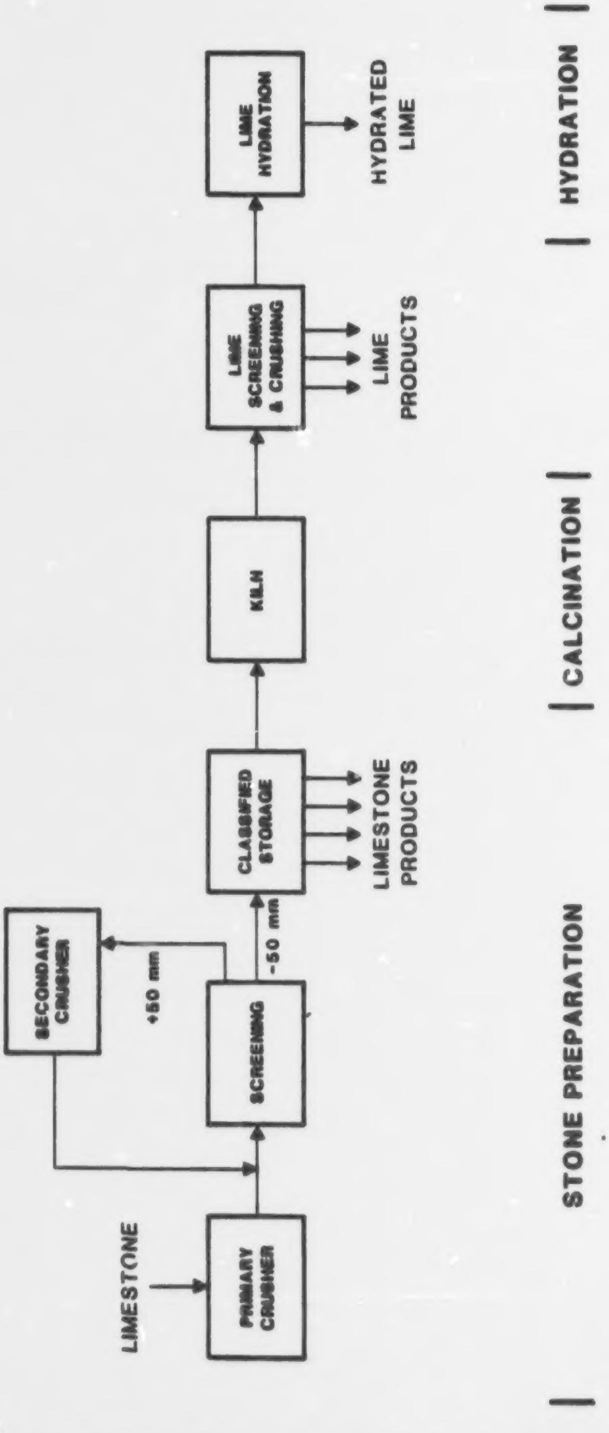
The kiln feed is made up by reclaiming given proportions of different sizes of limestone from the classified storage. The stone gradation determines the size distribution of the quicklime obtained after calcination. After cooling, quicklime may be stored as such, classified by screening or crushed. This further processing will be according to customers' specifications. Quicklime is shipped directly to customers in bulk containers by train or truck.

Production of hydrated lime involves supplementary processing steps:

- crushing,
- mixing quicklime and water,
- removal of impurities and uncalcined cores by air classification.

Figure I - LIME PROCESS FLOW SHEET

DOMTAR JOLIETTE PLANT


LIMESTONE
PRIMARY CRUSHER
SCREENING
+50 mm
SECONDARY CRUSHER
-50 mm
CLASSIFIED STORAGE
LIMESTONE PRODUCTS
KILN
LIME SCREENING & CRUSHING
LIME PRODUCTS
LIME HYDRATION
HYDRATED LIME
STONE PREPARATION
CALCINATION
HYDRATION

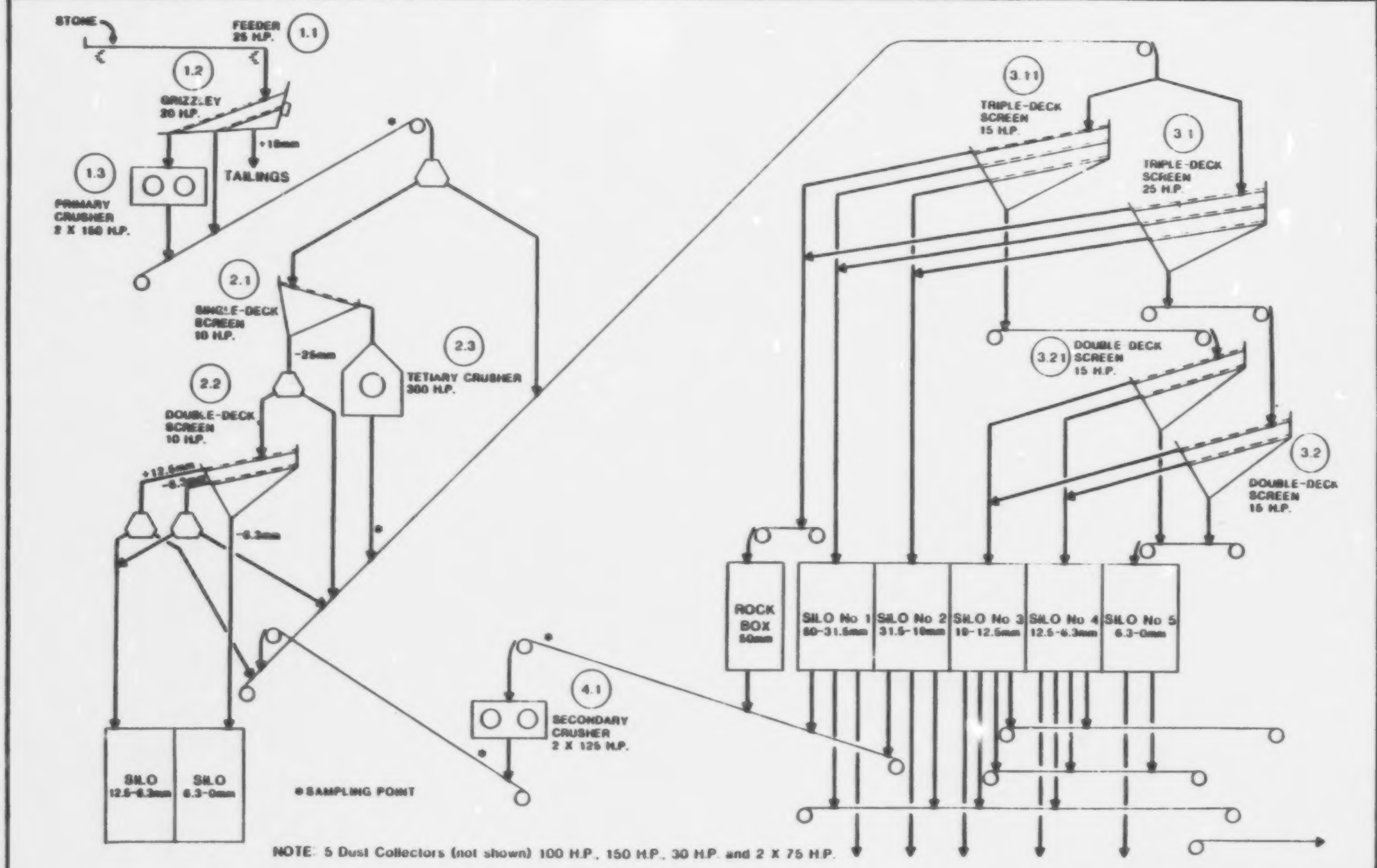
3.2 Limestone Crushing and Classification

The limestone processing at the Joliette plant is illustrated by the flow diagram in Figure II. The equipment that was monitored during the study is listed in Table 3.

The limestone crushing and screening circuit is capable of producing lime-type stone at a rate of over 500 t/h. This throughput, in fact, is dependent on the truck fleet transporting rocks from the quarry (four trucks were in use during the period of observation). Impact crushers are used for size reduction as their angular products are preferred by the aggregate industry.

Primary crushing is an open circuit composed of a reciprocating feeder, a vibrating double-decker grizzly and a Cedarapids double impeller impact breaker, Model 4350H. The impact breaker is powered by two 150 HP motors. The large dust collecting capacity is powered by a 100 HP motor.

When producing aggregates or construction stone where larger quantities of the smaller fractions are desirable, the stone flow passes the equipment numbered 2.1 to 2.4 on the sketch. The equipment used for these products comprises a set of two screens and another crusher used to reduce the oversize. During the observations this equipment was not operational, except for the dust collector powered by a 75 HP motor.


STONE
FEEDER
25 H.P.
1.1
1.2
GRIZZLEY
20 H.P.
+10mm
TAILINGS
1.3
PRIMARY
CRUSHER
2 X 150 H.P.
2.1
SINGLE-DECK
SCREEN
10 H.P.
-25mm
2.3
TETIARY CRUSHER
300 H.P.
2.2
DOUBLE-DECK
SCREEN
10 H.P.
+12.5mm
-6.3mm
SILO
12.5-6.3mm
SILO
6.3-0mm
● SAMPLING POINT
4.1
SECONDARY
CRUSHER
2 X 125 H.P.
3.11
TRIPLE-DECK
SCREEN
15 H.P.
3.1
TRIPLE-DECK
SCREEN
25 H.P.
3.21
DOUBLE DECK
SCREEN
15 H.P.
3.2
DOUBLE-DECK
SCREEN
15 H.P.
ROCK
BOX
50mm
SILO No 1
50-31.5mm
SILO No 2
31.5-19mm
SILO No 3
19-12.5mm
SILO No 4
12.5-6.3mm
SILO No 5
6.3-0mm

NOTE: 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

CANADA CEMENT LAFARGE LTD.
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20/04/83

CHECKED DCS
20/09/84

FIGURE II
LIMESTONE CRUSHING & SCREENING
FLOW DIAGRAM

PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q

PROJECT No. 20010

TABLE 3 - LIMESTONE CRUSHING AND SCREENING PLANT - EQUIPMENT LIST (COMMINUTION ONLY)

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	RECIPROCATING FEEDER	25	24
1.2	VIBRATING GRIZZLY	20	20
1.3	PRIMARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 4350H	150 150	150 150
1.4	DUST COLLECTOR - 25,000 CFM	100	100
2.1	VIBRATING SCREEN - SINGLE DECK -5' X 10' HEWITT-ROBINS M-11	10	10
2.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS M-11	10	10
2.3	TERTIARY CRUSHER - PULVOMATIC IMPACTOR - 4000 volts	300	40
2.4	DUST COLLECTOR - 15,000 CFM	75	75
3.1	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	25	25
3.11	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.21	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.3	DUST COLLECTOR (SCREENING PLANT) 30,000 CFM	150	150
3.4	DUST COLLECTOR (CONVEYORS) - 5,000 CFM	30	30
4.1	SECONDARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 3645	125 125	125 125
4.2	DUST COLLECTOR - 15,000 CFM	75	75

Note: All motors are 550 volts, except where noted.

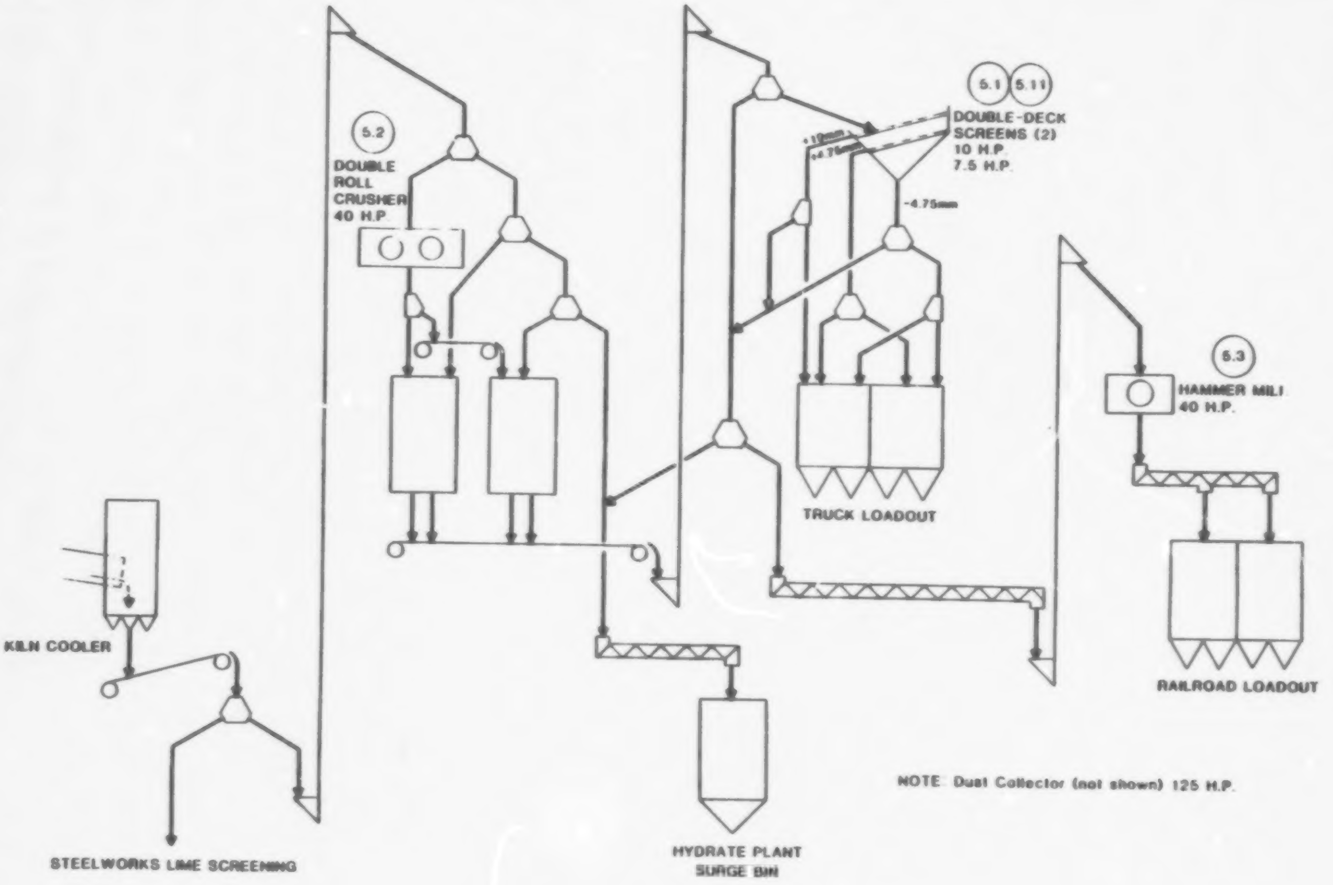
For lime production, the crushed stone is transferred to the main screening plant (equipment numbers starting with a 3 in the diagram) where the stone is classified into five size fractions and stored in 180 tonne silos. The stone classification is effected by dividing the flow between two sets of two screens, the first being a triple deck and the second a double deck. The oversize fraction (plus 50 mm) is fed to a Cedarapids double impeller impact breaker, Model 3645, powered by two 125 HP motors, which serves as a secondary crusher placed in closed circuit with the screening plant. The dust collector fan motors are large with a total installed power of 255 HP.

3.3 Lime Crushing and Screening

The essential steps of lime processing are illustrated in the flow diagram of Figure III. This diagram is a simplification of the actual handling system. Most equipment is duplicated, except for the rolls crusher and the hammermill. Lime can be either stored, screened or crushed before being put in a loadout silo. It can also be directed to the steelworks lime screening or the hydrate plant.

The equipment monitored in the lime handling department is listed in Table 4.

The equipment consists of two double-deck vibrating screens, one 40 HP Pioneer double roll crusher and one 40 HP Jeffrey hammermill. To be noted again is the importance of the power installed for dust collection.


5.2
DOUBLE ROLL CRUSHER 40 H.P.
5.1
5.11
DOUBLE-DECK SCREENS (2) 10 H.P. 7.5 H.P.
+19mm
+4.75mm
-4.75mm
5.3
HAMMER MILL 40 H.P.
KILN COOLER
TRUCK LOADOUT
RAILROAD LOADOUT
STEELWORKS LIME SCREENING
HYDRATE PLANT SURGE BIN
NOTE: Dust Collector (not shown) 125 H.P.

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DRAWN FGM DATE 21/04/83 CHECKED DCS DATE 20/09/84	FIGURE III LIME CRUSHING & SCREENING FLOW DIAGRAM	PLANT PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q PROJECT No. 20010

TABLE 4 - Lime Crushing and Screening

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	10	10
5.11	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	7.5	8
5.2	DOUBLE ROLL CRUSHER - PIONEER	40	40
5.3	HAMMERMILL - JEFFREY 2420	40	40
5.4	DUST COLLECTOR - 28,000 CFM	125	125

The steel industry specifies a pebble lime with minimal content of fines (minus 6.3 mm). Therefore, this lime is processed separately by applying a screening operation twice to remove the minus 6.3 mm fraction.

The process flow is depicted in the flow diagram of Figure IV. The equipment monitored were only the two double-deck vibrating screens with characteristics listed as follows:

TABLE 5 - Steelworks Lime Screening

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
6.1	VIBRATING SCREEN - DOUBLE DECK - 4' x 10' C-E TYLER TY-ROCK	10	10
6.2	VIBRATING SCREEN - DOUBLE DECK - $2m^2$ ROYER/MOGENSEN (ELECTRICALLY VIBRATED)	2 x 3	5.1

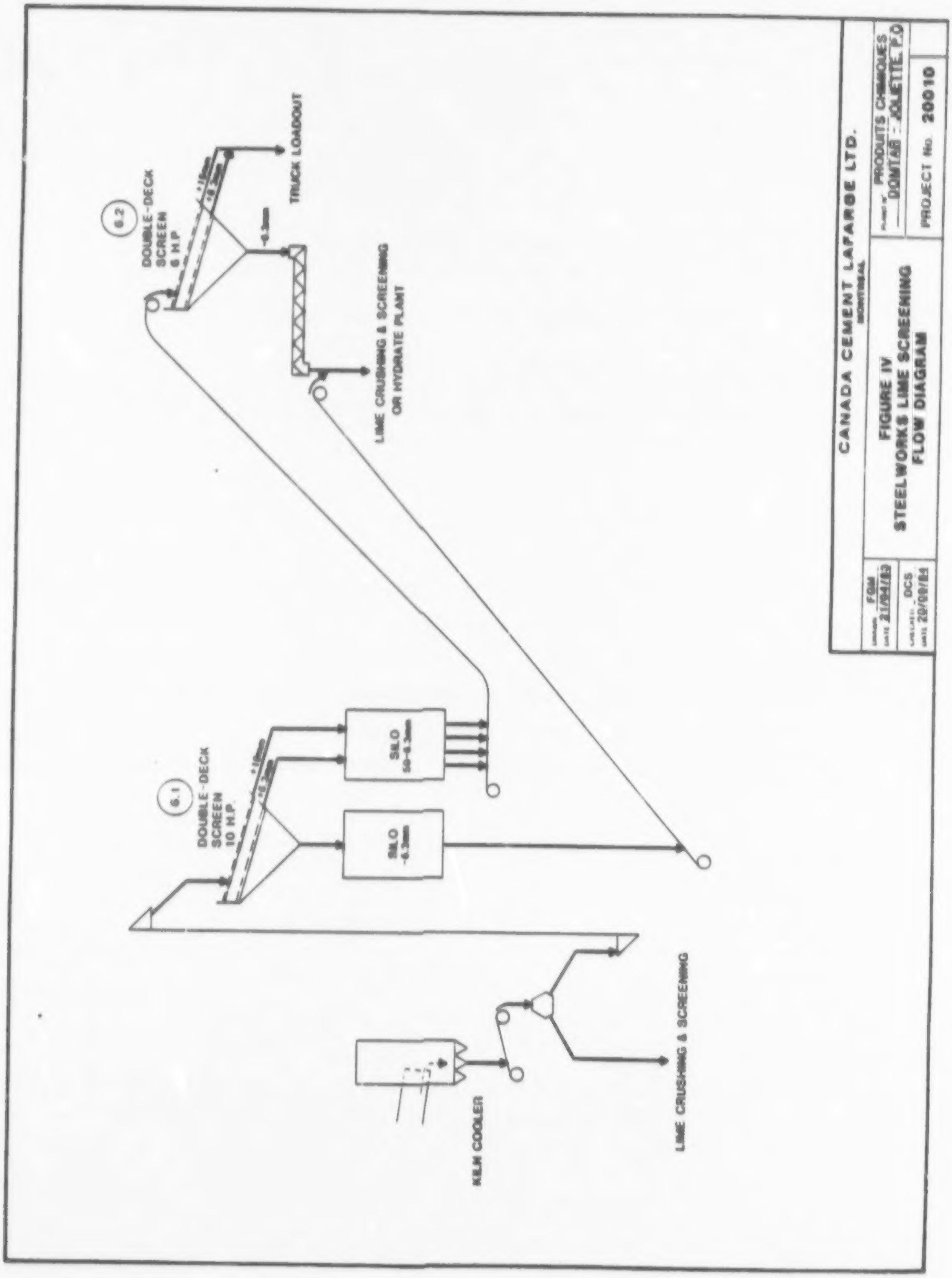

6.2
DOUBLE-DECK
SCREEN
6 H.P.
+19mm
+6.3mm
-6.3mm
TRUCK LOADOUT
LIME CRUSHING & SCREENING
OR HYDRATE PLANT
6.1
DOUBLE-DECK
SCREEN
10 H.P.
+19mm
+6.3mm
SILO
50-6.3mm
SILO
-6.3mm
KILN COOLER
LIME CRUSHING & SCREENING
CANADA CEMENT LAFARGE LTD.
MONTREAL
PRODUITS CHIMIQUES
DOMTAR - JOLIETTE P.Q
PROJECT No. 20010
DRAWN FGM
DATE 21/04/83
CHECKED DCS
DATE 20/09/84

FIGURE IV
STEELWORKS LIME SCREENING
FLOW DIAGRAM

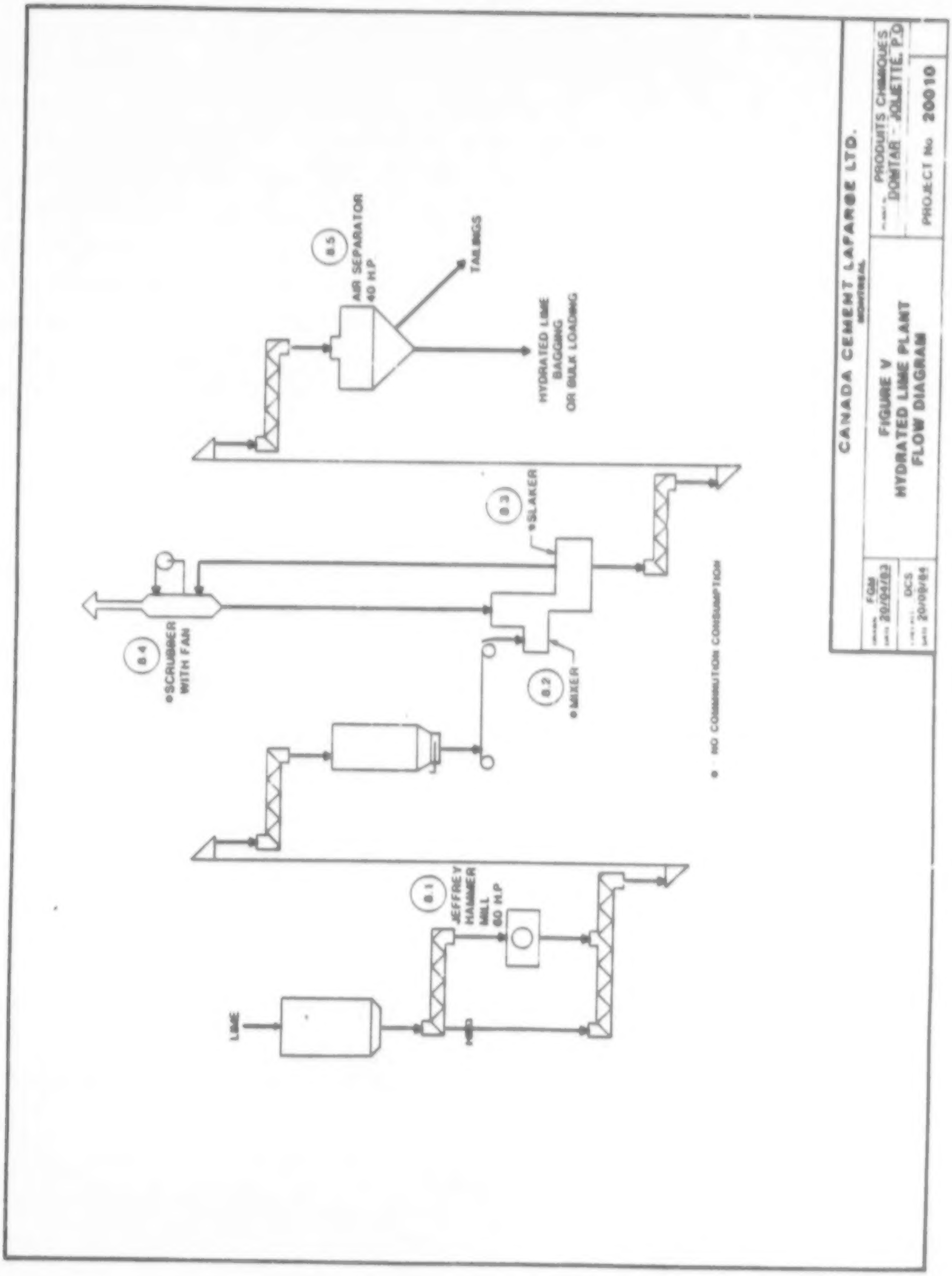
3.4 Hydrated Lime Plant

A simplified process flow is shown in the flow diagram of Figure V. To shorten the reaction time, lime is crushed in a 60 HP Jeffrey hammermill before being fed to the mixer. For the hydration of lime, sufficient water must be added for the hydration reaction. Well-proportioned quantities of lime and water are introduced to a mixing chamber (8.2) where a slurry is formed before being transferred to the hydrator proper (8.3) in which the chemical reaction takes place. This reaction is highly exothermic and generates large amounts of steam and dust that are recuperated and returned to the mixer by a scrubber (8.4) using a specially designed fan-washer.

Once hydrated, an air separator is used to remove coarse particles of impurities and unhydrated lime. Only the hammermill and separator were monitored.

TABLE 6 - Hydrated Lime Plant

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
8.1	HAMMERMILL - JEFFREY 2430	60	60
8.2	MIXER	-	-
8.3	LIME HYDRATOR	-	-
8.4	SCRUBBER WITH FAN	-	-
8.5	AIR SEPARATOR - 14' GAYCO	40	38


LIME
H2O
8.1
JEFFREY HAMMER MILL 60 H.P
8.2
• MIXER
8.3
• SLAKER
8.4
• SCRUBBER WITH FAN
8.5
AIR SEPARATOR 40 H.P
TAILINGS
HYDRATED LIME BAGGING OR BULK LOADING
• NO COMMINUTION CONSUMPTION
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE V
HYDRATED LIME PLANT
FLOW DIAGRAM
FGM
20/04/83
DCS
20/09/84
PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q
PROJECT No 20010

4. RESULTS AND DISCUSSION

The results of the data collection campaign are grouped under the following main headings, limestone crushing and screening, and lime crushing and screening.

4.1 Limestone Crushing and Screening

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the limestone crushing and screening circuit is presented in Table 7.

TABLE 7 - Limestone Crushing and Screening

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
1.1	FEEDER	25	8	1	2
1.2	GRIZZLY	20	8	8	8
1.3	PRIM. CRUSHER	150	138	6	90
		150	270	12	122
1.4	DUST COLLECTOR	100	51	51	51
2.4	TERT. CRUSHER DUST COLLECTOR	75	52	52	52
3.1	TRIPLE-DECK SCREEN	25	8.9	8.9	8.9
3.11	TRIPLE-DECK SCREEN	15	6.7	6.7	6.7
3.2	DOUBLE-DECK SCREEN	15	4.5	4.5	4.5
3.21	DOUBLE-DECK SCREEN	15	4.5	4.5	4.5
3.3	DUST COLLECTOR (SCREENS)	150	32	32	32
3.4	DUST COLLECTOR (CONVEYORS)	30	11.4	11.4	11.4
4.1	SEC. CRUSHER	125	44	12	28
		125	18	18	18
4.2	DUST COLLECTOR	75	26	26	26

The power level observations for the crushers, the feeder and the grizzly screen were obtained during a sufficiently long period of power level recording for the respective equipment. Typical examples are available in the working papers.

The following table summarizes the electrical measurements in terms of crusher motor loading. The primary crusher is well loaded while the secondary crusher works lightly.

TABLE 8 - Crusher Motor Load

CRUSHER	% NOMINAL POWER
Primary	94.7
Secondary	24.7

The power demand for dust collectors is large and totals 172 kW.

4.12 Flowrates

The flowrates of the limestone crushing and screening circuit have been determined by using the quarry truck-load count.

Three days of operation were used. The count of trucks during a day is multiplied by the average truckload weight (established by weighing randomly 6 to 9 trucks during the day) to give the overall day production. The total production for each of the three days, based on 8-hour shifts, was as listed below.

DATE	PRODUCTION (tonnes)
April 4	2507
April 6	3384
April 7	2706

The hours of actual operation during this period of three 8-hour shifts totalled 17.45 hours and the average production rate is thus calculated at 492.6 t/h. The actual production rate, when the primary crusher is continuously fed, is estimated at 680 t/h. This does not take into account any stoppage and could be called the potential flowrate. Such a potential flowrate cannot be directly translated in capacity without assuming a reasonable value for the utilization factor. By using this potential production rate the average production rate observed during three days represents an utilization factor of over 72%. These results are summarized in the following table.

PRIMARY CRUSHER FLOWRATE	
POTENTIAL FLOWRATE, t/h	680
AVERAGE FLOWRATE, t/h	493
UTILIZATION FACTOR, %	72.4

The flowrate through the secondary crusher was determined by taking two simultaneous belt-cut samples before and after this crusher. A 1.83 m cut weighing 51.43 kg was taken on belt #6 and a 1.63 m cut weighing 41.45 kg, on belt #7. Using the measured belt speeds which were respectively 127.1 m/min for belt #6 and 137.2 m/min for belt #7, the following flowrates were determined:

SECONDARY CRUSHER FLOWRATE	
BELT #6 SAMPLING, t/h	214.5
BELT #7 SAMPLING, t/h	209.8

The secondary crusher capacity is estimated at 210 t/h.

The average flowrate of the secondary crusher is estimated a 152 t/h and is obtained by multiplying the flowrate at full production by the circuit utilization factor.

4.13 Size Distribution

A typical product size distribution for the crushing circuit product is given in the following table:

CIRCUIT PRODUCT SIZE DISTRIBUTION	
mm	% passing
50.0	100
31.5	86
19.0	64
12.5	41
6.3	20

The size range of the primary crusher feed was minus 1250 mm, plus 150 mm and mainly minus 600 mm, plus 300 mm.

The primary crusher product was not sampled but its size distribution can be estimated through an approximate material balance of the circuit. For this purpose, the evaluation of the secondary crusher flowrate as well as its feed and product size distributions have been used. This has led to the following estimated size distribution.

PRIMARY CRUSHER PRODUCT SIZE DISTRIBUTION	
mm	% passing
150	100
100	94
50	72
25	45
12.5	25
6.3	12

The secondary crusher feed and product size distributions were both sampled and the following table presents a summary of the feed and product size distributions.

SECONDARY CRUSHER FEED AND PRODUCT SIZE DISTRIBUTIONS		
mm	% feed passing	% product passing
132.5	100	
100	80	
75	60	100
50	13	87
38.1	3	79
25		58
19		46
12.5		31
9.5		24

More detailed results are available in working papers.

4.14 Grindability Testing

The grindability tests on the limestone by both the Hardgrove and Bond test procedures were conducted at the CCL Belleville laboratory.

The Hardgrove Index (HGI) is 83. The Bond Index was determined to be. 8.86 kWh/Ton.

A typical HGI value for limestone would be in the range of 50-70 which gives an average computed Bond Index of 10.48 kWh/Ton.

4.15 Specific Energy Consumption

The procedure usually used to calculate the specific energy consumption consists in adding up the average power demand of each motor and dividing this total power demand by the average production rate. But, in the case of a crushing operation fed irregularly by truckloads, some caution is required in using the average power demand of a crusher motor as observed on power charts. The average power demand observed is not a true representation of power consumed during a full hour of production: this is due to idle running when no feed is supplied to the primary crusher. The observed power demand must therefore be adjusted down to take into account the non-productive time: the utilization factor previously discussed in 4.12 is used to this effect. Another equivalent approach would be to use the potential flowrate (also discussed in 4.12) as the true instantaneous production rate. This adjustment concerns only the primary crusher.

Accordingly, the average power demand of the primary crusher totalling 212 kW when fully loaded is adjusted by the utilization factor of 0.724 to 153.5 kW. This value is then added to the secondary crusher power demand (46 kW) and the total divided by the average production rate (492.6 t/h) to give a figure of 0.405 kWh/tonne for crushing only.

To this figure must be added the specific consumption of all other motors (auxiliaries) obtained by dividing the total non-crushing average power demand by the average production rate. This amounts to 0.420 kWh/tonne. Then the total circuit specific consumption is the sum of these two figures and totals 0.825 kWh/tonne.

Table 9 summarizes the data developed above and Table 10 gives a distribution of the power consumption between crushing, screening and dust collecting.

TABLE 9 - Limestone Crushing and Screening Specific Power Consumption

	kWh/tonne	%
Crushing Only	0.405	49.1
Auxiliaries	0.420	50.9
Total	0.825	100.0

TABLE 10 - Limestone Crushing and Screening Distribution of Consumption

	%
Crushing Only	49
Screening	9
Dust Collecting	42

The consumption for crushing alone is found to be very low and it must be viewed in relation with the coarse product size (minus 50 mm). On the other hand, auxiliaries and particularly dust collecting account for about half of total consumption. This high proportion can be reduced by increasing the utilization factor at the primary crusher so that the crusher motors are not idling while auxiliary motors are running at constant load. But the reduction in specific consumption would be slight. The alternative would be to examine the potential for reducing the power demand of dust collectors, at least when the primary crusher is idling.

4.2 Lime Processing

4.21 Electrical Measurements

A summary of the electrical measurements obtained on the lime crushing and screening operations is presented in Table 11. These power level observations were estimated for the most part by using the measured amperage and assuming a power factor value. Only two of the crushers were monitored with the recording wattmeter.

TABLE 11 - Lime Processing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN	AVG.
5.1	DOUBLE-DECK SCREEN	10	3	3	3
5.11	DOUBLE-DECK SCREEN	7.5	4	4	4
5.2	ROLL CRUSHER	40	5	5	5
5.3	HAMMERMILL	40	7	7	7
5.4	DUST COLLECTOR	125	70	70	70
6.1	DOUBLE-DECK SCREEN	10	3	3	3
6.2	DOUBLE-DECK SCREEN	6	4	4	4
8.1	HAMMERMILL	60	14	14	14
8.5	AIR SEPARATOR	40	16	16	16

The measurements show the low level of power consumption, particularly on the crushers which are run by sizeable motors. The hammermills use a flywheel to stabilize the mechanical load and as a consequence have a high starting power demand. Another observation is the high power load involved in dust collecting (No. 5.4) which results from the extensive and sophisticated lime handling system serving the lime discharge of three kilns. But it would be unfair to attribute to the lime crushing and screening operation the whole power demand of the dust collector; only a fraction of this demand would be needed for the air volume handled for both the roll crusher and hammermill. As this air volume is estimated at 5780 m^3/h and represents about 12% of the dust collector nominal capacity of 47570 m^3/h, only this fraction of the observed 70 kW (or 8.5 kW) will be used in calculating the specific consumption. Finally, the screens are shown to represent very small electrical loads.

4.22 Flowrates

There are basically three lime processing routes: the crushing and screening of minus 4.75 mm (-3/16") lime, the screening of steelworks lime and the preparation of lime for hydration.

The flowrates needed to compute specific power consumptions are listed in Table 12. They are based on plant records and were not actually measured.

TABLE 12 - Lime Flowrates

PROCESS UNIT	t/h
Raw Lime Screening (5.1)	14.5
3/16 Inch Lime Crushing (5.3)	8.5
Steelworks Lime - 1st Screening (6.1)	16.8
Steelworks Lime - 2nd Screening (6.2)	136
Hydrate Plant (8.1 & 8.5)	14.5

4.23 Size Distribution

Two crushing operations are involved: the production of minus 4.75 mm lime and the preparation for the production of hydrated lime.

In the production of minus 4.75 mm lime, the feed of the crusher consists of a plus 19 mm fraction accounting for one third of the feed and a minus 4.75 mm fraction accounting for two thirds. This feed results from the screening of raw lime whereby the mid-fraction is extracted and sold as a product.

The crushed product obtained has the following size distribution:

3/16 INCH LIME SIZE DISTRIBUTION	
mm	% passing
6.70	100
4.75	95
2.36	80
1.18	65
0.60	45

For lime used for hydration, the feed of the crusher can be a raw kiln product, a screened fraction or fines recuperated from dust collection. The fineness of the crushed lime is minus 2.36 mm.

4.24 Grindability Testing

Grindability tests on lime by both the Hardgrove and Bond test procedures were conducted. The test results, as expected, show it to be extremely easy to grind. The Hardgrove Index (HGI) was determined to be 165. The Bond test gave a value of 4.2 kWh/Ton.

4.25 Specific Energy Consumption

Table 13 gives the specific power consumption obtained for lime crushing and screening depending on the lime produced. The specific consumption of the 3/16 inch lime takes into account raw lime screening and dust collection, the latter established on an 8.5 kW demand. In the case of hydrated lime, the auxiliary equipment is the air separator.

TABLE 13 - Lime Processing Specific Power Consumption

	3/16" Lime		Steelworks Lime		Hydrated Lime	
	kWh/t	%	kWh/t	%	kWh/t	%
Crushing	0.82	36.0	-	-	0.97	47.5
Auxiliaries	1.46	64.0	0.20	100	1.07	52.5
Total	2.28	100	0.20	100	2.04	-

These data show lime crushing and screening power consumption to be rather low. As for limestone crushing, auxiliaries account for about half of total consumption. It is striking to note that the lime crushing specific consumption is roughly double that of limestone crushing. This would suggest that the crushers are probably underfed.

The overall lime product power consumption, including limestone crushing, is given in Table 14.

TABLE 14 - Lime Products Power Consumption Cumulative Specific Consumption

	3/16" Lime		Steelworks Lime		Hydrated Lime	
	kWh/t	%	kWh/t	%	kWh/t	%
Crushing	1.60	41.3	0.78	43.6	1.74	47.9
Auxiliaries	2.27	58.7	1.01	56.4	1.89	52.1
Total	3.87	100.0	1.79	100.0	3.63	100.0

These calculations take into account the yield factor of the calcining process, i.e. one tonne of limestone yields 0.52 tonne of quicklime and conversely 1.92 tonne of limestone is used to obtain one tonne of lime product.

The power consumption for total comminution, including auxiliaries, in the lime industry is low at just under 4 kWh/tonne. Moreover, a large part of lime production does not require crushing but only screening to remove fines (steelworks lime).

From company records, total consumption was estimated to average 31 kWh/tonne of product. Assuming 3 kWh/tonne, comminution including auxiliaries would represent about 10% of the total electric energy consumption.

In summary, there is no great potential for electrical energy savings in the lime industry.

The study has brought out the importance of the power consumption attributable to air pollution control. This was established clearly in limestone crushing and screening where dust collection accounts for 42% of total power consumption.

Savings would be had by reducing air flows through dust collectors when crushers are idling. A system can be engineered that would automatically close down dampers during idle periods. This would reduce power demand on fan motors for an appreciable amount of time.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and Its Processing

Lime is a term that should actually be used only to identify calcined limestone. This is also known as quicklime or calcium oxide (CaO). A secondary product of quicklime is hydrated lime or slaked lime ($Ca(OH)_2$).

Basically, there are two types of limestone: high calcium ($CaCO_3$) and high magnesium (dolomitic) ($CaCO_3.MgCO_3$) limestones. High calcium quicklime contains usually 0.5 to 2.5% magnesium oxide while dolomitic quicklime contains 35 to 40% magnesium oxide.[1]

Most quicklimes (CaO) correspond in size to the original crushed rock which varies from 25 to 200 mm and as such is called lump lime. Crushed or pebble lime is a product ranging in size from 6 to over 60 mm. Screened quicklime fines are sometimes compressed (pelletized) into one-inch pellets. For some purposes, ground or pulverized forms of quicklime are used, ranging from 2 mm to dust.[1]

Since quicklime has great affinity for moisture and carbon dioxide, it is perishable. As a chemical material it is desirable to reduce atmospheric exposure during handling and storage to a minimum. Lime is usually consumed within a few weeks of manufacture.[2]

Hydrated lime is more stable. It is obtained by adding water to quicklime hydrating it into a dry, fine, subsieve size white powder. Because its affinity for moisture has been satisfied, it is not as vulnerable to moisture as quicklime. However, it has the same strong affinity for carbon dioxide.[2]

Lime's extensive use in industry has made it second to sulfuric acid in tonnage among basic chemicals. However, in the early 1900's it was regarded primarily as a building material for mortar and plaster; over 80% was used in building construction. But today, the chemical and industrial uses account for more than 90% of lime consumption, with building construction uses comprising only 8% - a complete end-use reversal.[2]

Production of lime involves three main processes: stone preparation, calcination and hydration. The principal carbonate rocks used by industry are limestone and dolomite. Limestones are sedimentary rocks composed mostly of calcite ($CaCO_3$) and dolomites are sedimentary rocks composed mostly of dolomite ($CaCO_3.MgCO_3$). High-purity limestone and dolomite represent the raw materials of the lime industry. Because lime must meet exacting chemical specifications, the various steps in stone production are carefully controlled to prevent contamination with undesirable impurities, particularly silica, alumina, and iron oxide.[2]

"Quicklime (CaO or $CaO.MgO$) is formed by calcination in which limestones are heated to the dissociation temperature of the carbonates (as low as 402°C for $MgCO_3$ and as high as 898°C for $CaCO_3$) and held at that temperature over sufficient time to release carbon dioxide. Secondary products are slaked lime and hydrated lime. Slaked lime is the product of mixing quicklime and water; hydrated lime is slaked lime dried and possibly reground."[3]

Canadian Industry[3]

"Lime is a high-bulk and comparatively low-cost commodity. It is uncommon to ship it long distances because the raw material for its manufacture is available in many localities. The preferred location for a lime plant is near the principal lime markets, adjacent to a source of high-quality raw material and close to a supply of energy."[3]

The more heavily populated and industrialized provinces of Ontario and Quebec together produced over 80 percent of Canada's total lime output in 1980, with Ontario contributing about two-thirds of Canada's total.

Recent lime production statistics are given in Table 1 below. The distribution by province is also given in this table.

TABLE 1 - Canada, Lime Production and Trade, 1980 and 1982[3]

	1981		1982P	
	(tonnes)	($000)	(tonnes)	($000)
PRODUCTION[1]				
By Type				
Quicklime	2 359 000	142,070	2 010 000	..
Hydrated Lime	196 000	11,804	181 000	..
Total	2 555 000	153,874	2 191 000	148 861
By Province				
Ontario	1 773 000	106,815	1 463 000	99,484
Quebec	365 000	21,956	329 000	22,444
Alberta	183 000	11,047	159 000	10,812
British Columbia	111 000	6,671	107 000	7,077
Manitoba	..	4,450	..	5,100
New Brunswick	..	2,935	..	3,944
Total	2 555 000	153,874	2 191 000	148,861

Sources: Energy, Mines and Resources Canada; Statistics Canada.
[1] Producers' shipments and quantities used by producers.
P Preliminary; - Nil; .. Not available.

Production figures do not include some captive production such as that from pulp and paper plants that burn sludge to recover lime for reuse. With the addition of some new and larger capacity in recent years the industry could produce about 3.5 million tonnes per year.

The evolution of lime production, trade and apparent consumption during the last decade can be seen from Table 2. The apparent consumption has increased steadily but at a slow rate. Exports have more than doubled during this period.

TABLE 2 - Canada Lime Production, Trade and Apparent Consumption, 1970, 1975-82[3]

(tonnes)

Year	Quick	Hydrated	Total[1]	Imports	Exports	Consumption[2]
1970	1 296 590	224 026	1 520 616	30 649	181 994	1 369 271
1975	1 533 944	199 195	1 733 139	30 099	234 034	1 529 204
1976	1 703 374	227 019	1 930 393	36 282	309 355	1 657 920
1977	1 767 406	232 638	2 000 044	24 480	359 540	1 664 984
1978	1 857 580	176 631	2 034 211	31 130	478 552	1 586 789
1979	1 662 405	196 920	1 859 325	41 480	490 863	1 409 942
1980	2 364 000	190 000	2 554 000	40 901	403 166	2 191 735
1981	2 269 000	194 000	2 463 000	23 046	431 002	2 055 044
1982P	2 010 000	181 000	2 191 000	15 963	281 137	1 925 826

Sources: Energy, Mines and Resources Canada; Statistics Canada.
[1] Producers' shipments and quantities used by producers.
[2] Production, plus imports, less exports.
P Preliminary.

The Canadian lime producing companies are listed in Table 3. Those producing for a captive use are indicated. They concern mainly sugar beet processing and metal producing companies.

It is also noteworthy that three companies, Domtar Inc., Steetley Industries Ltd., and Steel Brothers Canada Ltd. have operated, in recent years, production facilities in the United States.

TABLE 3 - Canadian Lime Industry, 1982[3]

PROVINCE & COMPANY	PLANT LOCATION	TYPE OF QUICKLIME
New Brunswick		
Havelock Processing Ltd.	Havelock	High-calcium[2]
Quebec		
Domlim Inc.	Lime Ridge	High-calcium[2]
	St. Adolphe de Dudswell	High-calcium
Domtar Inc.	Joliette	High-calcium[2]
Gulf Canada Ltd., Shawinigan Chemical Division	Shawinigan	High-calcium[2]
Quebec Sugar Refinery[1]	St. Hilaire	High-calcium
Ontario		
The Algoma Steel Corp. Ltd.[1]	Sault Ste Marie	High-calcium & dolomitic
Allied Chemical Canada, Ltd.[1]	Amherstburg	High-calcium
BeachviLime Limited	Beachville	High-calcium
Guelph DoLime Limited	Guelph	Dolomitic[2]
Chromasco Limited[1]	Haley	Dolomitic
Domtar Inc.	Beachville	High-calcium[2]
Reiss Lime Co. of Canada Ltd.	Spragge	High-calcium
Stelco Inc.	Ingersoll	High-calcium
Steetley Industries Limited	Dundas	Dolomitic
Manitoba		
The Manitoba Sugar Co. Ltd.[1]	Fort Garry	High-calcium
Steel Brothers Canada Ltd.	Faulkner	High-calcium
Alberta		
Canadian Sugar Factory Ltd.[1]	Taber	High-calcium
	Picture Butte	High-calcium
Steel Brothers Canada Ltd.	Kananaskis	High-calcium[2]
Summit Lime Works Limited	Hazell	High-calcium & dolomitic[2]
British Columbia		
Steel Brothers Canada Ltd.	Kamloops	High-calcium
Texada Lime Ltd.	Fort Langley	High-calcium

Source: Energy, Mines and Resources Canada.

[1] Production for captive use.

[2] Hydrated lime produced also.

Market Outlook

Lime is used principally in the steel, pulp and paper, and mining industries where its chemical qualities are required as a flux, in digesting liquors and as a neutralizing agent, respectively. A typical distribution by use is given in Table 4.

TABLE 4 - Canada, Consumption of Lime, Quick and Hydrated, 1980 and 1981 (Producers' Shipments and Quantities Used by Producers, By Use)[3]

	1980		1981P	
	(tonnes)	($000)	(tonnes)	($000)
Chemical and Metallurgical				
Iron & steel plants	1 169 281[2]	59,166	1 237 519[2]	74,529
Pulp & paper mills	303 484	15,356	271 945	16,378
Water & sewage treatment	113 219	5,729	22 760[3]	1,371
Nonferrous smelters	113 818[2]	5,759	117 632[2]	7,085
Cyanide & flotation mills	68 805[2]	3,481	(4)	(4)
Sugar refineries	19 006	962	25 841	1,556
Other industrial[1]	643 531	32,563	690 040	41,557
Agricultural	17 084[3]	864	17 370	1,046
Road stabilization	8 716[3]	441	9 338[3]	565
Other uses	97 056	4,911	162 555	9,787
Total	2 554 000	129,232	2 555 000	153,874

Sources: Statistics Canada; Energy, Mines and Resources Canada.

[1] Includes glassworks, fertilizer plants, tanneries, uranium plants and other miscellaneous industrial uses.

[2] Figures represent quicklime only. Figures for hydrated lime are included in "other industrial" to avoid disclosing confidential company information.

[3] Figures represent hydrated lime only. Figures for quicklime are included in "other uses".

[4] Confidential figures are included in "other industrial works".

P Preliminary.

The largest single market for lime is provided by the metallurgical industry, particularly by the steel industry which has afforded during the past decade the largest increase in lime consumption. With increased application of the basic oxygen furnace (BOF) and of the electric arc furnace, lime consumption has increased greatly in certain areas of the United States and Canada. The pulp and paper industry is currently the second-largest consumer of lime, most of which is used in the preparation of digesting liquor and in pulp bleaching.

Lime is also used in many sectors of the mining and metal processing industry serving in various ways for the beneficiation of ores, the extraction of metals or as a neutralizing agent. There are many other uses of lime as a chemical or as a raw material but they cannot all be described in this study.

Future expansion is foreseen in the field of environmental pollution control, particularly in the treatment of water supplies and sewage or in the removal of sulphur dioxide from stack gases.

Chemical lime designates a type of quick or hydrated lime low in impurities and possessing a high degree of reactivity making it suitable for use in chemical processes. In industry the value of lime for most purposes is dependent on its content of available lime (CaO). The purity of lime is influenced primarily by the quality of the limestone and secondly, by its method of manufacture. The majority of limestones used for lime manufacture averages around 98 percent total carbonates. The chief impurities are silica, alumina and other metal oxides, in particular iron and manganese oxides. These impurities react with some of the calcium oxide in the kiln producing mineral forms (silicates, aluminates, etc) that are unavailable for chemical uses. Consequently, the purest quicklimes have available lime contents of 94-96 percent. Typical analyses of commercial limes are shown in the following table.[2]

TABLE 5 - Typical Analyses of Commercial Quick Limes

Component	High Calcium Quicklimes Range* %	Dolomitic Quicklimes Range* %
CaO	93.25 - 98.00	55.50 - 57.50
MgO	0.30 - 2.50	37.60 - 40.80
SiO_2	0.20 - 1.50	0.10 - 1.50
Fe_2O_3	0.10 - 0.40	0.05 - 0.40
Al_2O_3	0.10 - 0.50	0.05 - 0.50
H_2O	0.10 - 0.90	0.10 - 0.90
CO_2	0.40 - 1.50	0.40 - 1.50

Source: Chemical Lime Facts, National Lime Association[1]

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* The values given in this range do not necessarily represent minima and maxima.

Hydrated limes are produced in a purer form than quicklime, since in the milling of the dry hydrate air separation devices are used which remove most of the coarse particles - namely "core" (unburned carbonates), silicates and aluminates. As a result, hydrates of 72 to 74 percent available lime are produced with chemically combined water content of 23 to 24 percent.[2]

The other impurities in limestone are trace elements which are monitored according to the end-use of lime and to customer's specification. These are sulfur, phosphorus, arsenic, manganese, strontium and fluorine.

Quicklime is commercially available in bulk or bags, in a number of more or less standard sizes as follows.[1,2,4]

Lump lime - Usually the product of various vertical kiln processes ranging in size from 90 to 200 mm.

Pebble lime - Usually the product of rotary kiln ranging in size from 6.3 to 63 mm.

Ground lime - Typically the size gradation is about 100% passing 2.36 mm and 2-4% passing 150 µm. It is a sized kiln product or the result of grinding and classifying coarser sizes.

Pulverized - Typical size gradation is about 100% passing 850 µm and 85-95% passing 150 µm. Usually this product is a secondary product and is the direct result of pulverization and classification.

Briquettes (pelletized)	- These are 25 mm sized pellets or briquettes molded from quicklime fines.

Hydrated lime is generally shipped in 25-kilo paper bags,in bulk tank trucks or rail cars. Due to the hydration process hydrated lime is by necessity of fine particle size. Normal grades of hydrate will have 85% or more passing 75 µm, while for special applications air classified hydrated lime may be obtained as fine as 99.5% passing 45 µm.

Most of the product specifications are user-oriented. Within the industry three criteria appear to be the most common. They are: available lime content (calcium oxide), sulphur content and particle size.

The greater the purity of the lime, the more desirable it is for chemical uses. This quality feature depends largely on the purity of limestone, i.e. on minimal impurity content, particularly silica and alumina. A correlated criterion is the chemical reactivity which is dependent on many interrelated factors among which are the burning process, the degree of burning, the grain size of limestone, etc. This property of lime is estimated by measuring the loss on ignition of quicklime. A more reactive lime is a soft-burned lime still containing some residual CO_2. But excessive underburning indicated by a core of uncalcined limestone (over 2% LOI) implies a decrease in the available lime content.

The measurement of Available Lime Index is done by a method called the "Rapid Sugar Test", described in the ASTM specification C25-79 "Standard Methods of Chemical Analysis of Limestone, Quicklime and Hydrated Lime".[4]

For some industrial purposes, sulphur content may be the most important criterion. This is particularly the case in the steel making industry where it is desirable to use a lime with minimal sulphur content. In this most important market, lime is in fact used as a flux to purify steel by removing mainly phosphorus and sulphur. In other industrial uses, sulphur content is not an important criterion.

The particle size of lime is generally an important criterion depending on the end use. Again, the steel industry requires usually a lime in pebble form containing no fines (minus 6.3 mm). Other industries using lime in chemical processes will specify crushed lime or fines so that the rate of solution is increased. Still, other industries prefer to use a narrow distribution of small-size pebble lime, typically a 6.3 to 19.0 mm distribution.

Lime users do not typically care about the size distribution or any criteria of specific surface area measurement. A maximum size limit is usually specified. Size distribution is determined through standard mechanical sieving on sieve sizes established in ASTM E11-70 specification. The lime industry has generally standardized on 45 µm as being the lowest practical sieving limit for reasonable accuracy. The standard dry sieving method is satisfactory for quicklime but unsatisfactory for hydrated lime. With the latter, a wet sieving procedure is strongly recommended.[4]

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REFERENCES

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LIMESTONE

[illegible] Plastidex [illegible]

THE LIMESTONE INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

DSS File Number: 23SQ.23440-2-9016A
DSS Contract Serial Number: OSQ82-00228

TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 4

   2.1 General 2
   2.2 The Lime Division 2
   2.3 Products Marketed 3

3. PROCESS DESCRIPTION 5 - 12

   3.1 Limestone Product Process Flow 5
   3.2 Aggregate Crushing and Classification 5
   3.3 Limestone Pulverizing 10

4. RESULTS AND DISCUSSION 13 - 29

   4.1 Aggregate Crushing and Screening 13

      4.11 Electrical Measurements 13
      4.12 Flowrates 15
      4.13 Size Distribution 19
      4.14 Grindability Testing 21
      4.15 Specific Energy Consumption 21

   4.2 Agricultural Stone Pulverizing 23

      4.21 Electrical Measurements 23
      4.22 Flowrate 24
      4.23 Size Distribution 24
      4.24 Specific Energy Consumption 25

   4.3 Filler Product Pulverizing 27

      4.31 Electrical Measurements 27
      4.32 Flowrate 27
      4.33 Size Distribution 27
      4.34 Specific Energy Consumption 28

5. CONCLUSIONS AND RECOMMENDATIONS 30 - 31

STEEP ROCK RESOURCES INC. CALCITE PLANT
   1. The Company
   2. Process Description
   3. Energy Consumption

APPENDIX - Industry Review
   1. General Information
   2. Product Characteristics
   3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Domtar Incorporated

Plant Location:

Joliette, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

The main report is supplemented by a brief description and comminution power requirement of the calcite processing operations of:

Steep Rock Resources Inc.
Perth, Ontario Plant.

For readers who are not familiar with the limestone industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

Domtar Inc. was approached as a representative limestone processor whose comminution operations could be monitored to build the data base required in the Phase I of the project. The lime plant located at Joliette, Quebec, was selected to conduct the data generation campaign.

2.1 General

Domtar Inc. is one of the largest industrial groups in Canada operating over 70 manufacturing plants distributed in Canada and the United States of America. The total sales of the company were close to $1.7 billion in 1982.

The large number of activities and products sold by this company are divided among five operating groups which can be listed in decreasing importance as follows:

1 -	Pulp and Paper	: 50% of sales
2 -	Construction Materials	: 19% of sales
3 -	Box and Packaging	: 15% of sales
4 -	Chemical Products	: 16% of sales
5 -	Energy Resources Investments	

2.2 The Lime Division

The limestone products are produced by the Lime Division which is one of four divisions forming the Chemical Products Group. Domtar's Lime Division is the largest lime producer in Canada. In 1982, with sales of $29 million, it accounted for more than 20% of total sales in Canada.

The production capacity is distributed over two plants, one in Ontario and one in Quebec.

The plant located at Joliette, Quebec, has a capacity of 300,000 tonnes per year and produces quick lime and hydrated lime as well as a variety of limestone products for construction and agricultural uses.

2.3 Products Marketed

Typical specifications for Domtar's limestone products are listed in Table 1.

Except for the pulverized limestone (minus 150 µm), mainly used as a filler material in the manufacture of roof shingles, the other products, aggregate stone and agricultural stone, are very seasonal. Nevertheless, the sales of aggregate stone can exceed 500,000 tonnes per year. Pulverized limestone used as filler material can reach 60,000 to 70,000 tonnes per year while agricultural and chemical limestone are each about 25,000 tonnes a year. Pulverized stone is marketed under the name of "Stalco" and agricultural stone under that of "Solpier".

TABLE 1 - Domtar - Joliette Lime Plant
Products Marketed
Limestone Products

1) Aggregate Stone

% Passing	31.5 x 50.0 mm	19.0 x 31.5 mm	12.5 x 19.0 mm	6.3 x 12.5 mm
50.0 mm	100			
38.1	61	100		
25.0	3	68	100	
19.0	1	14	86	100
12.5		2	18	99
9.5			3	56
4.75				3

2) Chemical Stone (0 x 6.3 mm)	- 96% $CaCO_3$	100% minus 6.7 mm 72% minus 3.35 mm 40% minus 1.00 mm 16% minus 150 µm
3) Agricultural Limestone (Solpier)	- 92% $CaCO_3$	100% minus 3.35 mm 80% minus 850 µm 41% minus 150 µm
4) Pulverized Limestone (Stalco)	-	99% minus 150 µm 85% minus 75 µm 70% minus 45 µm

3. PROCESS DESCRIPTION

3.1 Limestone Product Process Flow

The general limestone process flow sheet illustrated in Figure I is the one operated by the Domtar Joliette plant for the production of aggregates, agricultural stone and pulverized stone. Aggregate stone is produced by a crushing system comprising a series of crushers and screens leading ultimately to the classification of 19 mm stone and under.

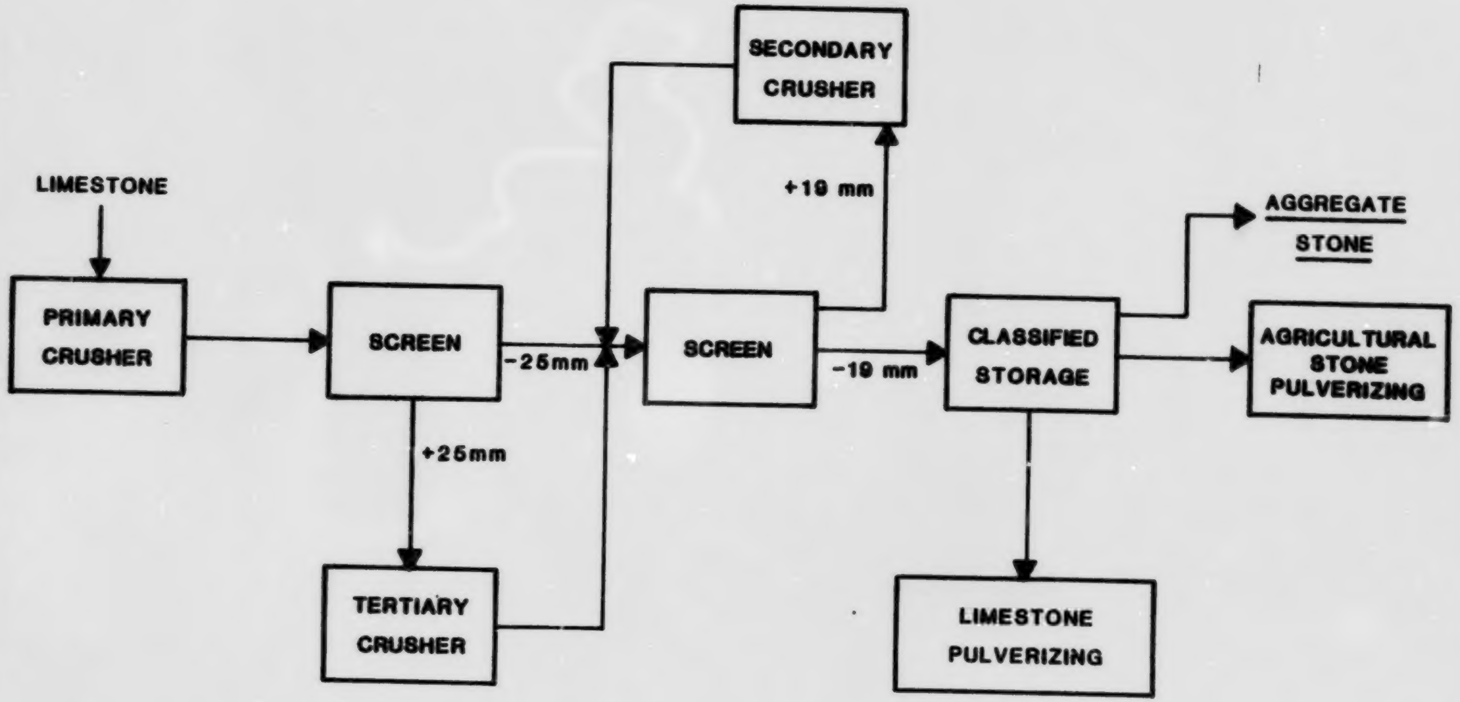
In this operation three crushers are used while stone preparation for lime making uses two crushers to produce a minus 50 mm stone. This explains why the product of the primary crusher is screened at a size of 25 mm and the oversize is reduced by an additional crusher, identified as the tertiary crusher. The product of this crusher is mixed with the undersize before being classified into final sizes, mainly under 19 mm. The secondary crusher serves to close the circuit by processing the oversize (plus 19 mm) remaining from the classification operation.

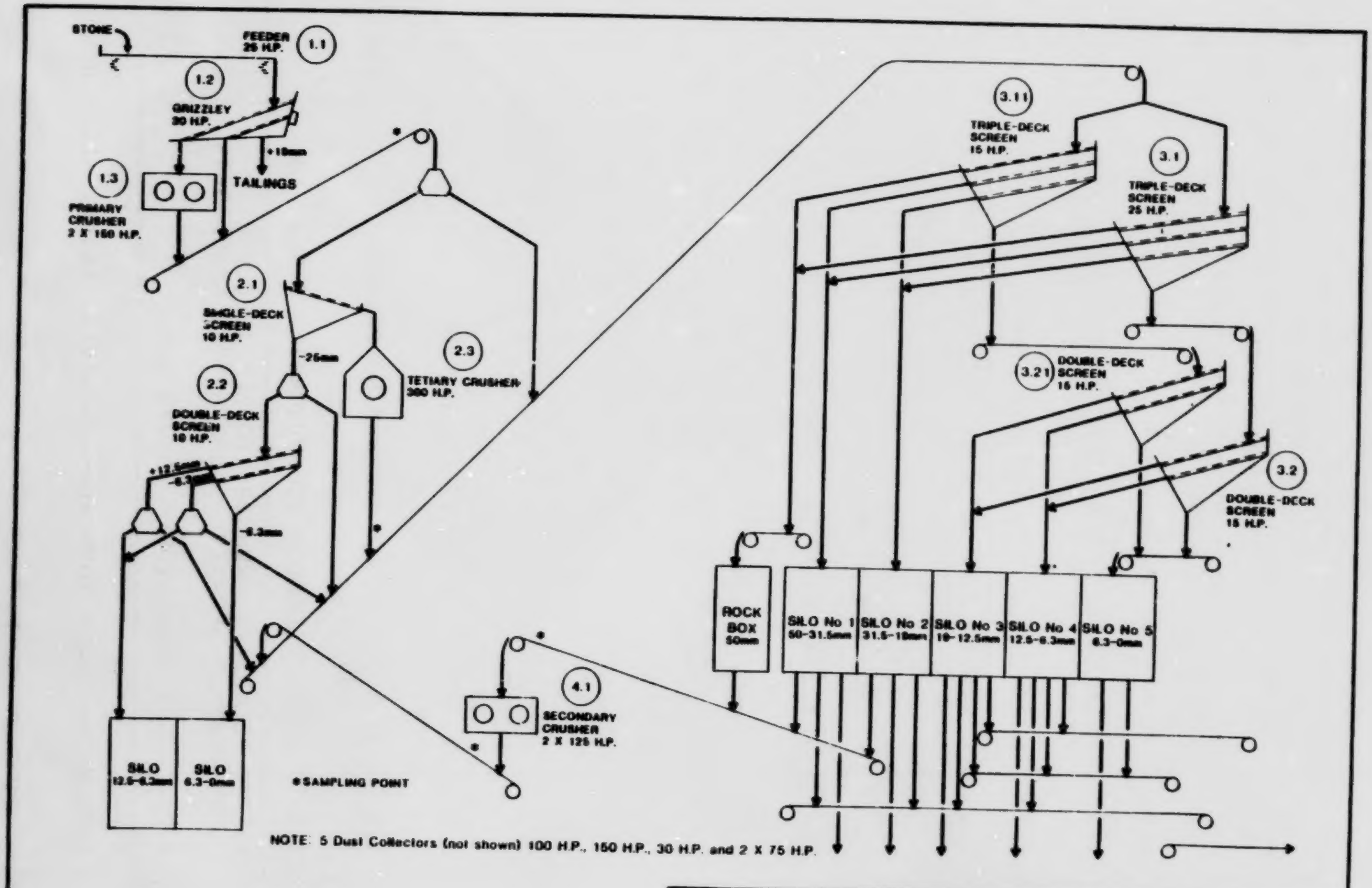
The minus 6.3 mm fraction is reclaimed from the classified storage and used as feed to the pulverizers that produce agricultural and pulverized stone.

3.2 Aggregate Crushing and Classification

The limestone processing is illustrated by the flow diagram in Figure II. The equipment that was monitored during the survey is listed in Table 2.

Figure I - LIMESTONE PROCESS FLOW SHEET
DOMTAR JOLIETTE PLANT


LIMESTONE
PRIMARY CRUSHER
SCREEN
-25mm
+25mm
TERTIARY CRUSHER
SCREEN
SECONDARY CRUSHER
+19 mm
-19 mm
CLASSIFIED STORAGE
AGGREGATE STONE
AGRICULTURAL STONE PULVERIZING
LIMESTONE PULVERIZING


STONE
FEEDER 25 H.P.
1.1
1.2
GRIZZLEY 30 H.P.
+10mm
TAILINGS
1.3
PRIMARY CRUSHER 2 X 150 H.P.
2.1
SINGLE-DECK SCREEN 10 H.P.
-25mm
2.3
TETIARY CRUSHER 300 H.P.
2.2
DOUBLE-DECK SCREEN 10 H.P.
+12.5mm
-6.3mm
-6.3mm
SILO 12.5-6.3mm
SILO 6.3-0mm
● SAMPLING POINT
4.1
SECONDARY CRUSHER 2 X 125 H.P.
3.11
TRIPLE-DECK SCREEN 15 H.P.
3.1
TRIPLE-DECK SCREEN 25 H.P.
3.21
DOUBLE-DECK SCREEN 15 H.P.
3.2
DOUBLE-DECK SCREEN 15 H.P.
ROCK BOX 50mm
SILO No 1 50-31.5mm
SILO No 2 31.5-19mm
SILO No 3 19-12.5mm
SILO No 4 12.5-6.3mm
SILO No 5 6.3-0mm

NOTE: 5 Dust Collectors (not shown) 100 H.P., 150 H.P., 30 H.P. and 2 X 75 H.P.

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DATE 20/09/84

FIGURE II
AGGREGATE CRUSHING & SCREENING
FLOW DIAGRAM

PLANT No. PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q.

PROJECT No. 20010

TABLE 2 - LIMESTONE CRUSHING AND SCREENING PLANT - EQUIPMENT LIST (COMMINUTION ONLY)

	EQUIPMENT	MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	RECIPROCATING FEEDER	25	24
1.2	VIBRATING GRIZZLY	20	20
1.3	PRIMARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 4350H	150 150	150 150
1.4	DUST COLLECTOR - 25,000 CFM	100	100
2.1	VIBRATING SCREEN - SINGLE DECK - 5' X 10' HEWITT-ROBINS M-11	10	10
2.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS M-11	10	10
2.3	TERTIARY CRUSHER - PULVOMATIC IMPACTORS - 48" 4000 VOLT	300	40
2.4	DUST COLLECTOR - 15,000 CFM	75	75
3.1	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	25	25
3.11	VIBRATING SCREEN - TRIPLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.2	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.21	VIBRATING SCREEN - DOUBLE DECK - 5' X 16' HEWITT-ROBINS	15	16
3.3	DUST COLLECTOR (SCREENING PLANT) 30,000 CFM	150	150
3.4	DUST COLLECTOR (CONVEYORS) - 5,000 CFM	30	30
4.1	SECONDARY CRUSHER: DOUBLE IMPELLER IMPACT BREAKER - CEDARAPIDS, MODEL 3645	125 125	125 125
4.2	DUST COLLECTOR - 15,000 CFM	75	75

Note: All motors are 550 volts, except where noted

Primary crushing is an open circuit composed of a reciprocating feeder, a vibrating doubledeck grizzly and a Cedarapids double impeller impact breaker, Model 4350H. The impact breaker is powered by two 150 HP motors. The large dust collecting capacity is powered by a 100 HP motor.

The primary crusher product is screened on a single deck screen having a 25 x 50 mm aperture. The oversize is reduced in a 48" Pulvomatic impactor powered by a 300 HP motor and identified as the tertiary crusher because it is only used when producing construction stone.The undersize can be screened again on a double deck screen for immediate storage of finished product (in that case, usually 6.3 x 12.5 mm and minus 6.3 mm stone). Generally, this double deck screen is not operated and the undersize of the single deck screen is conveyed to the main screening plant along with the tertiary crusher product. A dust collector fan powered by a 75 HP motor covers the needs in that area.

At that point the stone is all under 75 mm and it will be classified into five size fractions and stored in 180 tonne silos. The stone classification is effected by dividing the flow between two sets of two screens, the first being a triple deck and the second a double deck. The stone sizes are given in Figure II. The oversize fraction (plus 50 mm) excluded from storage is fed to a Cedarapids double impeller impact breaker, Model 3645, powered by two 125 HP motors. This crusher is identified as the secondary crusher because it is always kept operational, even when preparing stone for lime making, and is used to close the circuit with the screening plant. The coarsest sizes in the storage silos, i.e. the 31.5 x 50 mm and the 19 x 31.5 mm, are generally recirculated and added to the 50 mm oversize as feed to the secondary crusher. Trucks are also used to convey part of that stone back to the feed box of the primary crusher.

In that last portion of the crushing circuit three dust collectors are used with a total installed power of 255 HP.

The limestone crushing and screening circuit is capable of producing construction-type stone at a rate of over 400 tonnes per hour. This throughput, it must be noted, is dependent on the truck fleet transporting rocks from the quarry (four trucks were in use during the period of observation).

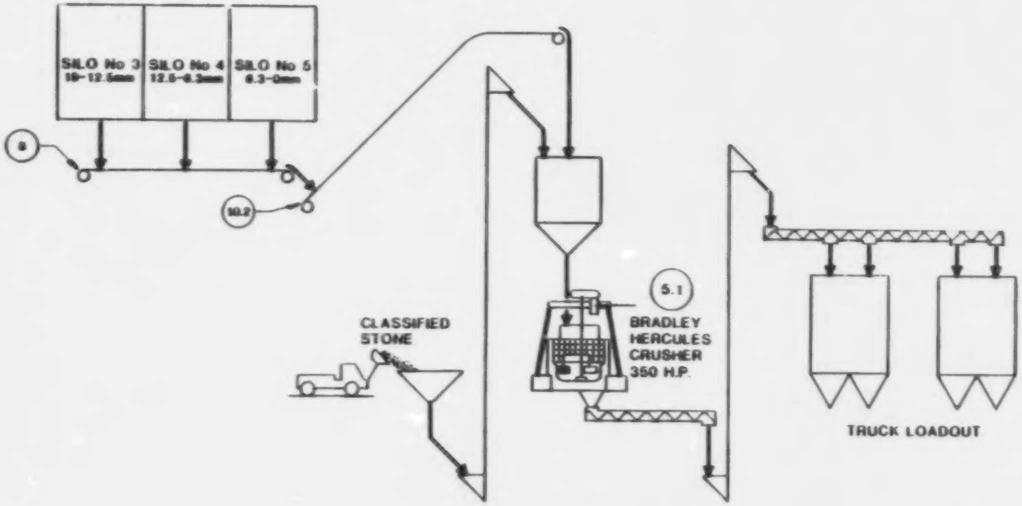
3.3 Limestone Pulverizing

Limestone pulverizing at the Joliette plant is rather a simple operation and could be termed more properly coarse grinding. Two types of products are involved, the agricultural stone and the pulverized stone marketed respectively under the names of "Solpier" and "Stalco". These products are obtained from two grinding plants whose flow sheets are illustrated in Figure III and Figure IV. The equipment involved is listed in Table 3.

TABLE 3 - Limestone Pulverizing Plants

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
5.1	Bradley Hercules - Type 6000 - 4000 Volts	350	51
5.2	Dust Collector (10,000 CFM)	25	25
6.1	Giant Griffin - 40" (x 2)	100	110
		125	130
6.2	Dust Collector	40	40

Note: All motors are 550 volt, except where noted.


SILO No 3
19-12.5mm
SILO No 4
12.5-6.3mm
SILO No 5
6.3-0mm
8
10.2
5.1
BRADLEY
HERCULES
CRUSHER
350 H.P.
CLASSIFIED
STONE
TRUCK LOADOUT

NOTE: Dust Collector (not shown) 25 H.P.

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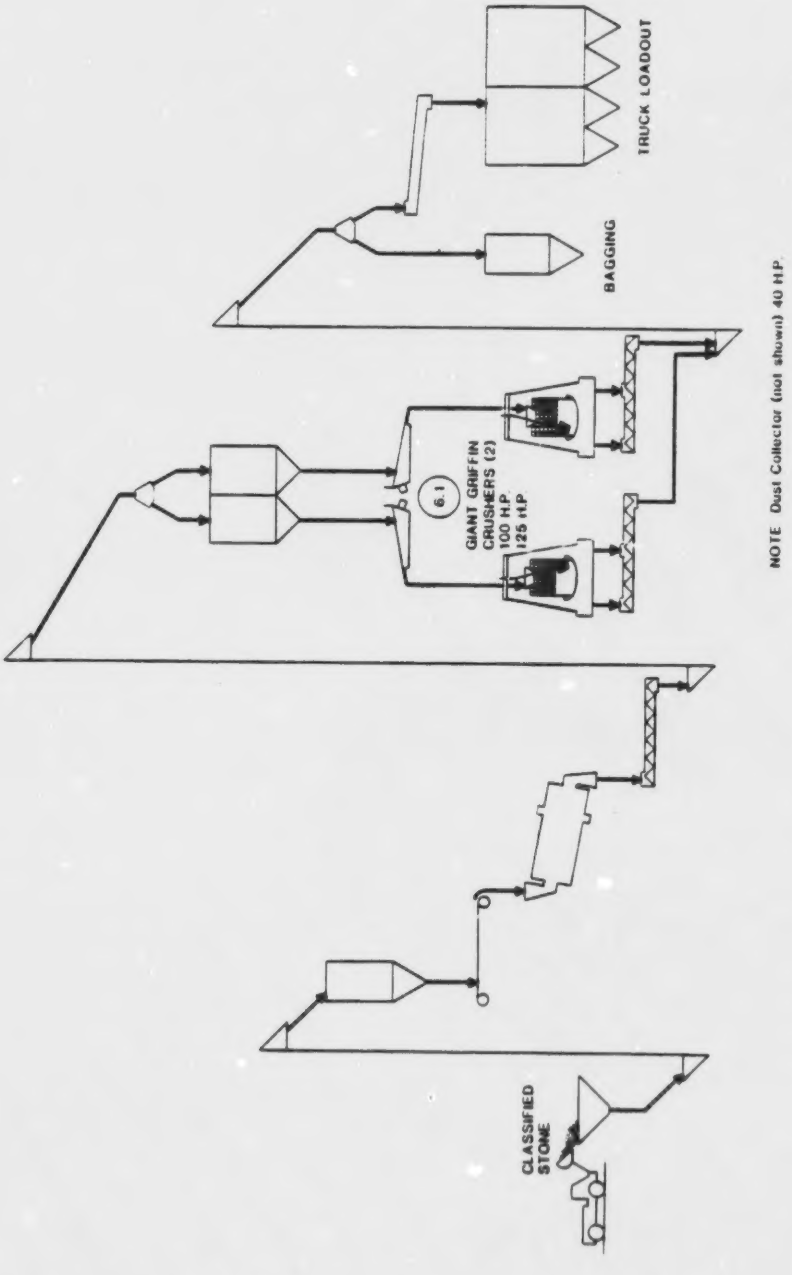
FIGURE III
LIMESTONE PULVERIZING (SOLPIER)
FLOW DIAGRAM

PRODUITS CHIMIQUES
DOMTAR - JOLIETTE, P.Q.

PROJECT No 20010


TRUCK LOADOUT
BAGGING
6.1
GIANT GRIFFIN
CRUSHERS (2)
100 H.P.
125 H.P.
CLASSIFIED
STONE

NOTE Dust Collector (not shown) 40 H.P.

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FIGURE IV
LIMESTONE PULVERIZING (STALCO)
FLOW DIAGRAM

PLANT PRODUITS CHIMIQUES DOMTAR - JOLIETTE, P.Q.

PROJECT No 20010

DRAWN FGM
DATE 26/09/83
CHECKED DCS
DATE 20/09/84

4. RESULTS AND DISCUSSION

The results of the data collection campaign are grouped under the following headings: aggregate crushing and screening, agricultural stone pulverizing and filler product pulverizing.

4.1 Aggregate Crushing and Screening

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the aggregate crushing and screening circuit is presented in Table 4.

TABLE 4 - Aggregate Crushing and Screening

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS-kW		
			MAX.	MIN.	AVG.
1.1	Feeder	25	8	1	2
1.2	Grizzly	20	8	8	8
1.3	Primary Crusher	150	267	6	74
		150	204	6	98
1.4	Dust Collector	100	48	48	48
2.1	Single-Deck Screen	10	5	5	5
2.3	Tertiary Crusher	300	365	50	195
2.4	Dust Collector	75	51	51	51
3.1	Triple-Deck Screen	25	8	8	8
3.11	Triple-Deck Screen	15	5	5	5
3.2	Double-Deck Screen	15	6	6	6
3.21	Double-Deck Screen	15	5	5	5
3.3	Dust Collector (Screen)	150	51	51	51
3.4	Dust Collector (Conveyor)	30	16	16	16
4.1	Secondary Crusher	125	66	48	54
		125	36	30	33
4.2	Dust Collector	75	28	28	28

The power level observations for the primary and secondary crushers, and for the screening plant dust collector, were obtained by recording each motor power demand during sufficiently long periods. Concerning the tertiary crusher, the average three-phase current was recorded.

An interesting comparison can be made between this set of observations and that of the circuit operation when preparing stone for lime making (see the report on the Lime Industry which presents the results of a previous data collection campaign). Table 5 presents such a comparison between the two crushing operations in terms of electric loading of the crusher motors (in percentage of nominal power).

TABLE 5 - Crusher Motor Load (% Nominal Power)

CRUSHER	AGGREGATE STONE (JUNE '83)	LIME MAKING STONE (APRIL '83)
Primary	76.9	94.7
Secondary	46.6	24.7
Tertiary	87.1	-

- The primary crusher feed is coarser in the case of the lime making stone than in that of the aggregate stone. The lime making stone is apparently harder to crush than the aggregate stone. Both factors combine to induce a higher power demand on the primary crusher.

- The product size aimed at for lime making (minus 50 mm) being already obtained for over 70% of the primary crusher product, little work is left for the secondary crusher.

- Conversely, for the aggregate stone, the product size aimed at (minus 19 mm) is obtained for only 35% of the primary crusher product; the tertiary crusher does most of the work as shown by the 87% loading and, this time, more work is left for the secondary crusher.

The power demand for dust collectors totals 194 kW, which is 13% more than observed for the lime making stone (172 kW). This increased power demand is caused solely by the two dust collectors at the screening plant, particularly the screens dust collector (51 vs 32 kW).

4.12 Flowrates

The flowrate of the aggregate crushing and screening circuit was determined by using the quarry truck loads.

Two eight-hour production shifts on June 2, 1983, were used to determine the production rate. The count of trucks during a shift is multiplied by the average truckload weight (established by weighing randomly 6 to 9 trucks) to give the overall shift production. The total production for these two shifts is listed below.

DATE	PRODUCTION (tonnes)
June 2 7-15 hour shift	2970
June 2 15-23 hour shift	2822

The average production rate of the crushing operation over the hours operated (14.33 h) was calculated at 404.1 t/h. But the actual production rate, when the primary crusher is continuously fed, is estimated at 680 t/h. Thus the average production rate represents a utilization factor of about 60% of the potential flowrate.

The determination of flowrates at other points in the circuit is based on a sampling plan which consisted of four simultaneous belt-cut samplings effected on conveyors 1, 2, 6 and 7. The samplings characteristics and the flowrates thus calculated are shown in the following table.

TABLE 6 - Material Sampling

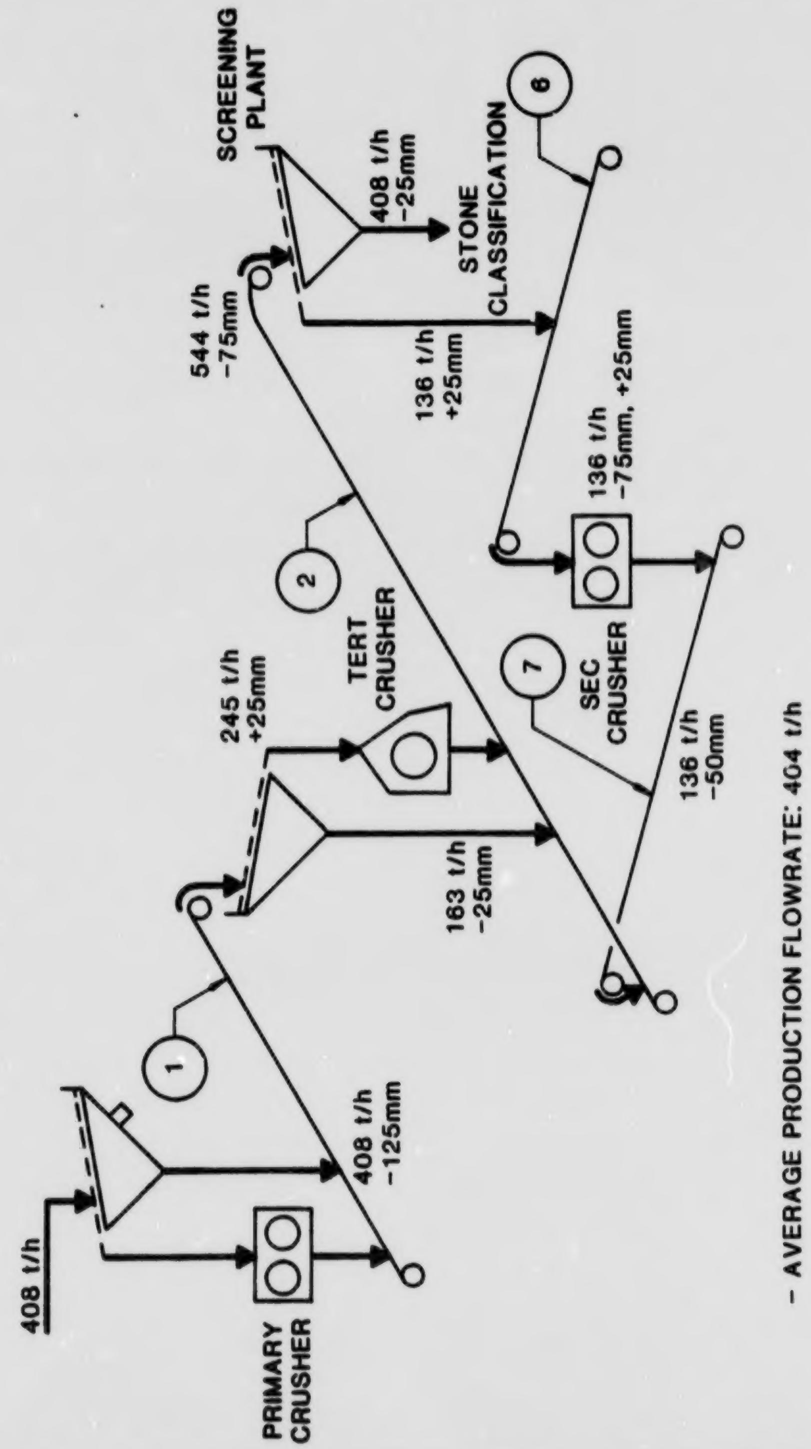
SAMPLING	CUT LENGTH	SAMPLE WEIGHT	BELT SPEED	MATERIAL FLOWRATE
POINT	m	kg	m/min	t/h
C-1	1.829	166.5	117.7	642.6
C-2	0.914	61.7	135.6	549.5
C-6	1.219	20.5	128.0	129.0
C-7	1.219	24.0	137.2	162.0

These calculated flowrates can be considered as close to average situation with the exception of the one found on conveyor C-1. The latter one can be explained by a sudden surge of material caused by a higher than average truck arrival rate, the circuit having been stopped under full load before a lunch break. This flowrate is confirmed by the fact that 7 truckloads were delivered to the primary crusher during the half-hour period preceding the circuit stoppage. If three truckloads were crushed during the last ten minutes, it would be equivalent to a flowrate of 607 t/h. The flowrate sampled on conveyor C-1 reinforces the view that the primary crusher can process up to 680 t/h as stated above.

Concerning the other calculated flowrates, the one found on C-2 is felt to be representative of the screening plant feed rate. But a sizeable discrepancy exists between the C-6 and C-7 flowrates which should represent the flowrate through the secondary crusher: this situation results probably from the surge condition observed at the primary crusher which was creating unstable flow conditions. The true average flowrate is necessarily between these two rates and, based on the study of the size distributions available, it is estimated at 136 t/h. This flowrate includes the recirculation of the stone screened and stored in silo No. 1 (31.5 x 50 mm) which makes up the greater part of this flow (about 80%).

To summarize the description of flowrates, a typical circuit operation is outlined in Figure V, showing average flowrates and sizes. A simplification is made by choosing arbitrarily a 25 mm mesh for the screening plant and the screen before the tertiary crusher. This dimension is thought to be closer to the true separation size of the actual 25 x 50 mm and 31.5 mm aperture screens. A circulating load estimated at 136 t/h comprises the recirculation of the stone stored in silo No. 1. The stone trucked from silo No. 2 to the primary crusher feed is not taken into account.

Figure V - AGGREGATE STONE PRODUCTION TYPICAL CIRCUIT OPERATION DIAGRAM


408 t/h
PRIMARY CRUSHER
408 t/h
-125mm
1
163 t/h
-25mm
245 t/h
+25mm
TERT CRUSHER
2
7
SEC CRUSHER
136 t/h
-50mm
544 t/h
-75mm
SCREENING PLANT
408 t/h
-25mm
STONE CLASSIFICATION
136 t/h
+25mm
6
136 t/h
-75mm, +25mm

- AVERAGE PRODUCTION FLOWRATE: 404 t/h

4.13 Size Distribution

The June 2-day shift production breakdown data (not reported here in detail) was used to derive a typical product size distribution for the crushing circuit. This distribution is given in the following table.

CRUSHING CIRCUIT TYPICAL PRODUCT SIZE DISTRIBUTION	
mm	% Passing
50.0	100
31.5	98.2
19.0	96.7
12.5	62.7
6.3	32.4

The size distribution of the primary crusher feed was minus 900 mm, plus 50 mm and mainly minus 450 mm, plus 150 mm.

The primary crusher production was sampled on conveyor C-1 as described earlier. The secondary crusher feed and product were also sampled on conveyors C-6 and C-7, respectively. But it was not feasible, due to production constraints, to sample the tertiary crusher feed and product; the size distributions for the latter have been estimated. The size distributions for the above mentioned steps in the comminution processes are grouped in Table 7.

The four size distributions that were determined at the Joliette plant laboratory are shown in working papers.

Data is given in Table 8 on the screening equipment being used to effect the classification of aggregates. The screens are identified by their equipment number as illustrated in Figure II.

TABLE 7 - Aggregate Crushing & Screening Circuit Size Distributions

mm	PRIM. CRUSHER PRODUCT % passing (1)	TERT. CRUSHER FEED % passing (2)	TERT. CRUSHER PRODUCT % passing (2)	SEC. CRUSHER FEED % passing (1)	SEC. CRUSHER PRODUCT % passing (1)
132.5	100	100			
100	96.1	93.5			
90	92.4	87.3		100	
75	88.9	81.5	100	98.4	100
63	84.3	73.8	95.6	95.9	97.3
50	74.3	57.2	93.3	82.0	95.2
38.1	61.1	35.2	86.0	70.1	92.8
25.0	43.6	6.0	55.3	3.9	64.0
19.0	34.4		38.3	1.4	47.6
12.5	25.2		24.8	1.0	33.2
9.5	20.3		18.1	0.9	25.9
4.75	11.8		8.7	0.8	14.3

(1) Sieve Analysis Tested
(2) Estimated

TABLE 8 - Screens Characteristic Data

EQUIPMENT No.	SCREEN DIMENSIONS m	APERTURE mm	WIRE DIAMETER mm	OPEN AREA %
2.1	1.52 x 3.05	25 x 50	9.53	61.2
2.2	1.52 x 4.88	12.5 x 12.5	4.50	54.5
-	-	6.3 x 6.3	2.03	57.4
3.1	1.52 x 4.88	50 x 50	11.12	67.3
-	-	31.5 x 31.5	9.53	59.2
-	-	19.0 x 19.0	5.26	61.4
3.2	1.52 x 4.88	12.5 x 12.5	4.50	54.5
-	-	6.3 x 6.3	2.03	57.4

4.14 Grindability Testing

The grindability testing by both the Hardgrove and Bond test procedures as conducted at the CCL Belleville laboratory. A chemical analysis was also made to ascertain that the tested limestone was really the aggregate stone with over 4% SiO_2 content (the so-called "Pierre Noire").

The Hardgrove Index (HGI) found on this limestone is 66 which is appreciably less than the value found on the lime making stone (83). The Bond Index gave a test value of 8.41 kWh/T, lower than the value found in the lime making stone (8.86 kWh/T). The calculated Bond Index was 9.61 kWh/T.

These results suggest that this limestone has a normal Work Index. For instance, a typical HGI value would be in the range of 50-70 giving an average computed Bond Index of 10.5 kWh/T. Relying on the HGI found, the aggregate stone would be harder to grind than the lime making stone (the so-called "Pierre Grise"), but this fact does not necessarily imply that it is also harder to crush; the opposite could well be the case.

4.15 Specific Energy Consumption

The procedure used to calculate the specific energy consumption consists simply in adding up the average power demand of each motor and dividing this total power demand by the average production rate. But, in the case of a crushing operation fed irregularly by truckloads, some caution is required in using the average power demand of a crusher motor as observed on power charts. The average power demand observed is not a true representation of power consumed during a full hour of production: this is due to idle running when no feed is supplied to the primary crusher. The observed power demand must therefore be adjusted down to take into account the non-productive time: the utilization factor (see Section 4.12) is used to this effect. Another equivalent approach would be to use the potential flowrate as the true instantaneous production rate. This adjustment concerns only the primary crusher.

Accordingly, the average power demand of the primary crusher totalling 172 kW when fully loaded is adjusted by the utilization factor of 0.60 to 103.2 kW. This value is then added to the secondary and tertiary crushers power demand (282 kW) and the total divided by the average production rate (404.1 t/h) to give a figure of 0.953 kWh/tonne for crushing only.

To this figure must be added the specific consumption of all other motors (auxiliaries) which is obtained by dividing the total non-crushing average power demand by the average production rate. This amounts to 0.576 kWh/tonne. The total circuit specific consumption, the sum of these two figures, is 1.53 kWh/tonne.

Table 9 summarizes the data developed above and Table 10 gives a distribution of power consumption between crushing, screening and dust collecting.

TABLE 9 - Aggregate Crushing and Screening Specific Power Consumption

	kWh/tonne	%
Crushing Only	0.953	62.2
Auxiliaries	0.577	37.8
Total	1.53	100.0

TABLE 10 - Aggregate Crushing and Screening Distribution of Consumption

	%
Crushing Only	62
Screening	7
Dust Collecting	31

The specific consumption for crushing alone (0.953 kWh/t) is comparable to other limestone crushing operations. In cement manufacture, a figure around 1.0 kWh/t is common for a reduction to minus 19.0 mm.

4.2 Agricultural Stone Pulverizing

4.21 Electrical Measurements

At the time of the survey, the agricultural stone pulverizing plant was not operational and as a consequence the Bradley 6000 Hercules pulverizer could not be monitored.

But typical operating electrical values were obtained from plant records; the data is presented in Table 11. The power factor values used to calculate the power consumption of the pulverizer and dust collector were 0.75 and 0.65, respectively.

TABLE 11 - Agricultural Stone Pulverizing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
5.1	Bradley 6000 Hercules	350	260	260	260
5.2	Dust Collector	25	9	9	9

From these values the Bradley pulverizer appears fully loaded and the dust collector power demand very low.

4.22 Flowrate

According to plant records, the production rate of the pulverizer is very steady and of the order of 41 t/h. This value is used to compute the specific power consumption.

4.23 Size Distribution

The feed to the pulverizer can be supplied from any of the silos No. 3, No. 4 or No. 5, with the last being the usual source. The size distributions for silos No. 3 and No. 4 were previously described in Table 1 under the 12.5 x 19.0 mm and 6.3 x 12.5 mm headings. Silo No. 5 size distribution is described briefly in the same table under the heading of Chemical Stone. But a more complete distribution is given below.

BRADLEY PULVERIZER FEED SIZE DISTRIBUTION	
mm	% Passing
6.7	100
4.75	86
3.35	72
2.36	58
1.18	40
0.600	29
0.300	24
0.150	16
0.075	12

As for the pulverizer product size, a partial distribution was given in Table 1 under the heading of Agricultural Limestone, but more details are given in the following table:

AGRICULTURAL STONE SIZE DISTRIBUTION	
mm	% Passing
3.35	100
2.36	99
1.70	94
0.850	80
0.250	52
0.150	41

4.24 Specific Energy Consumption

The electrical data reported in Table 11 and the production rate in 4.22 are used to compute the specific power consumption data for the pulverizer circuit and the cumulative consumption which is shown in Tables 12 & 13.

TABLE 12 - Agricultural Stone Pulverizing Circuit Specific Power Consumption

	kWh/tonne	%
Pulverizing	6.37	96.5
Dust Collecting	0.23	3.5
Total	6.60	100.0

TABLE 13 - Agricultural Stone Cumulative Power Consumption

	kWh/tonne	%
Crushing	0.95	11.6
Pulverizing	6.37	78.4
Auxiliaries	0.81	10.0
Total	8.13	100.0

The specific consumption for pulverizing alone is the energy consumed by the Bradley pulverizer while the term "pulverizing and crushing" is the total finished product energy consumption. The comminution work makes up 90% of the combined pulverizing and crushing consumption.

The performance of the Bradley pulverizer can be rated as excellent for the comminution work done. Its electrical load is maximum at 260 kW (almost 350 HP) and its production rate is most probably at a maximum at almost 41 t/h. This performance compares very well with past performances reported in Taggart's Handbook of Mineral Dressing for a similar mill grinding cement rock to minus 1.18 mm at 36.3 t/h with a 300 HP motor: the specific consumption amounted in that case to 6.2 kWh/tonne.

4.3 Filler Product Pulverizing

4.31 Electrical Measurements

One of the two Giant Griffin mills was monitored using the recording wattmeter. The electrical measurements are presented in Table 14. The dust collector is used by both mills; its power demand must be halved to calculate the consumption for a single mill.

TABLE 14 - Filler Product Pulverizing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
6.1	Giant Griffin	100	73	66	72
6.2	Dust Collector	40	14	14	14

From these power observations it is obvious that the Griffin mill operates fully loaded. By observing the amperage on the second Griffin mill it could be seen operating at the same loading for an equivalent production.

4.32 Flowrate

Production rate on each Griffin mill was reported to be very steady at 4.5 t/h. This value is used to compute the specific power consumption.

4.33 Size Distribution

The feed to the Griffin mill is the minus 6.3 mm stone obtained from silo No. 5 and of which the size distribution was given in 4.23.

A partial description of the product size distribution is given in Table 1 under the heading of Pulverized Limestone. Sedigraph analysis indicated that, at that time, the product was coarser than specifications: the minus 150 µm was 91% instead of 99%, the 75 µm was 74% instead of 85% and the 45 µm was 59% instead of 70%.

4.34 Specific Energy Consumption

The electrical data reported in Table 14 and the production rate in 4.32 are used to compute the specific power consumption data for the circuit and cumulative consumption for the product which are shown in Tables 15 & 16.

TABLE 15 - Filler Product Pulverizing Circuit Specific Power Consumption

	kWh/tonne	%
Pulverizing Only	15.9	91.4
Dust Collecting	1.5	8.6
Total	17.4	100.0

TABLE 16 - Filler Product Cumulative Power Consumption

	kWh/tonne	%
Crushing	0.95	5.1
Pulverizing	15.90	84.1
Auxiliaries	2.05	10.8
Total	18.9	100.0

The comminution work makes up 89% of the combined pulverizing and crushing consumption.

The performance of the Giant Griffin mills can also be rated as excellent, their electrical load being almost a maximum at 72 kW and the production rate at 4.5 t/h each. The Handbook of Mineral Dressing reports, for a similar type of mill grinding limestone to 95% passing 150 µm and using a 75 HP motor, a production rate of 3.2 t/h and a specific power consumption of 17.6 kWh/tonne.

The power consumption for total comminution, including auxiliaries, is low in the limestone processing operations of the Joliette plant reflecting the preponderance of aggregate production and low volumes of coarse grind products. In specific terms, it ranges from 1.5 kWh/tonne for aggregates classified in three sizes (19.0, 12.5, 6.3 mm) to 8.1 kWh/tonne for agricultural stone and 18.9 kWh/tonne for the filler product (90% passing 150 µm).

The cost involved is not a major factor in the manufacturing cost, particularly in the case of aggregates where it accounts for less than 5%. For the agricultural stone, the cost for comminution, including auxiliaries, represents less than 10% and for the filler product, the cost is about 15% of manufacturing cost.

In all cases, the potential for savings is small. This is particularly true for the two pulverizer operations where the grinding machines are used at full power and production rates have reached close to optimal rates at almost 41 t/h for agricultural stone and 4.5 t/h per mill for filler product. It is not as true in the case of the crushing circuit where the production rate could be somewhat higher by increasing further the utilization factor. Admittedly, this suggestion would have to be examined closely in relation to the screening and conveying capacity.

A possible improvement may be sought in the increase of throughput because the crusher motors have still some power margin left. Although this survey and its associated field work were not conducted during a period long enough to identify properly the circuit bottleneck, the scalping screen before the tertiary crusher and the tertiary crusher itself would appear to be the probable source of throughput limitation. The tertiary crusher was found highly loaded at 87% of nominal power and the scalping screen in the same situation due to its limited screening area (4.5 m^2).

A possible approach to ease these constraints may be to enlarge the screen opening in order to decrease the feed to the tertiary crusher and the loading on the motor at the present operating level. This change would transfer more work onto the secondary crusher which is the least loaded. As a consequence, the circuit overall throughput could be increased somewhat in the future subject to conveying capacity and quarry truck availability. The loading on motors of conveyors C-1 and C-2 at present operating level would have to be checked for spare capacity to ensure the feasibility of throughput increase.

STEEP ROCK RESOURCES INC. CALCITE PLANT
AT PERTH, ONTARIO

STEEP ROCK CALCITE
A DIVISION OF STEEP ROCK RESOURCES INC.

1. THE COMPANY*

1.1 General

Steep Rock Resources Inc. owns a calcite quarry property at Tatlock, Ontario, and a calcite processing plant at Perth, Ontario. The deposit is unique in its combination of favourable characteristics: magnitude, whiteness, high calcium content, low magnesium and silica contents, and scarcity of accessory minerals.

The Perth plant processes, in fact, a white marble which is crushed, dried, screened, dry ground and air classified into a wide range of products, from decorative stone chips to white fillers and extenders used in paint, plastic and joint compounds.

When Steep Rock Resources purchased this operation from W.R. Barnes Company Ltd. in December 1980, the main elements of the plant were a primary crusher, two screenhouses, a rotary dryer, a fine grinding section containing a 66-inch Raymond roller mill, air classifiers, bagging and bulk loadout facilities, and a warehouse.

A major expansion of the fine grind production capacity was undertaken in 1982 and put into production in mid 1983. This expansion provides greater flexibility as to product mix and reduces dependence on a single grinding equipment, the Raymond mill. In fact, before expansion, the Raymond mill system was producing through its integrated air classifiers four different products with particle top sizes of 76, 44, 25 and 15 µm, respectively. This system had necessarily a limited capacity to produce the finest sized and highest value products. After expansion, the dependency on the Raymond mill was removed by adding a new grinding circuit consisting essentially of a pebble mill with an integrated air separator, two high efficiency air classifiers, a new bulk loadout facility and other auxiliary equipment. This new pebble mill can accept feed directly from the second screenhouse and thus operate in parallel with the Raymond mill. But, generally, the latter produces a coarser product at a much higher and more efficient rate for further grinding in the pebble mill.

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* The information in this section is derived from a paper given at the 19th Forum on the Geology of Industrial Minerals, Ontario, Geological Survey, 1983.

The plant expansion provides a doubling of fine and medium fine grinding capacity allowing to satisfy projected market demand for these products. The expansion has been designed to be fully compatible with a possible future move into production of ultrafine calcite products.

1.2 Products

Three types of products are made: aggregate stone, screened sand-grade products, and fine and medium-fine grind products.

Aggregate products are the coarsest in size and the lowest in value, ranging from 16 by 31.5 mm down to minus 3.2 mm size. Typical uses for these products are decorative chips and driveway stone, terrazo chips, poultry grit and white block manufacturing.

Screened sand-grade products have finer sizes, ranging from 600 by 2400 µm to 75 by 425 µm. Typical uses include animal feed, stucco mix, cultured marble, floor tile and ashtray sand.

Fine and medium-fine grind products have the smallest particle size and highest value. The coarsest medium-fine grind product is 80% minus 45 µm. The finest of the present fine grind products has a particle top size of 15 µm. These products are used as fillers in paint, plastics, rubber, joint compounds, adhesives and other industrial products.

2. PROCESS DESCRIPTION

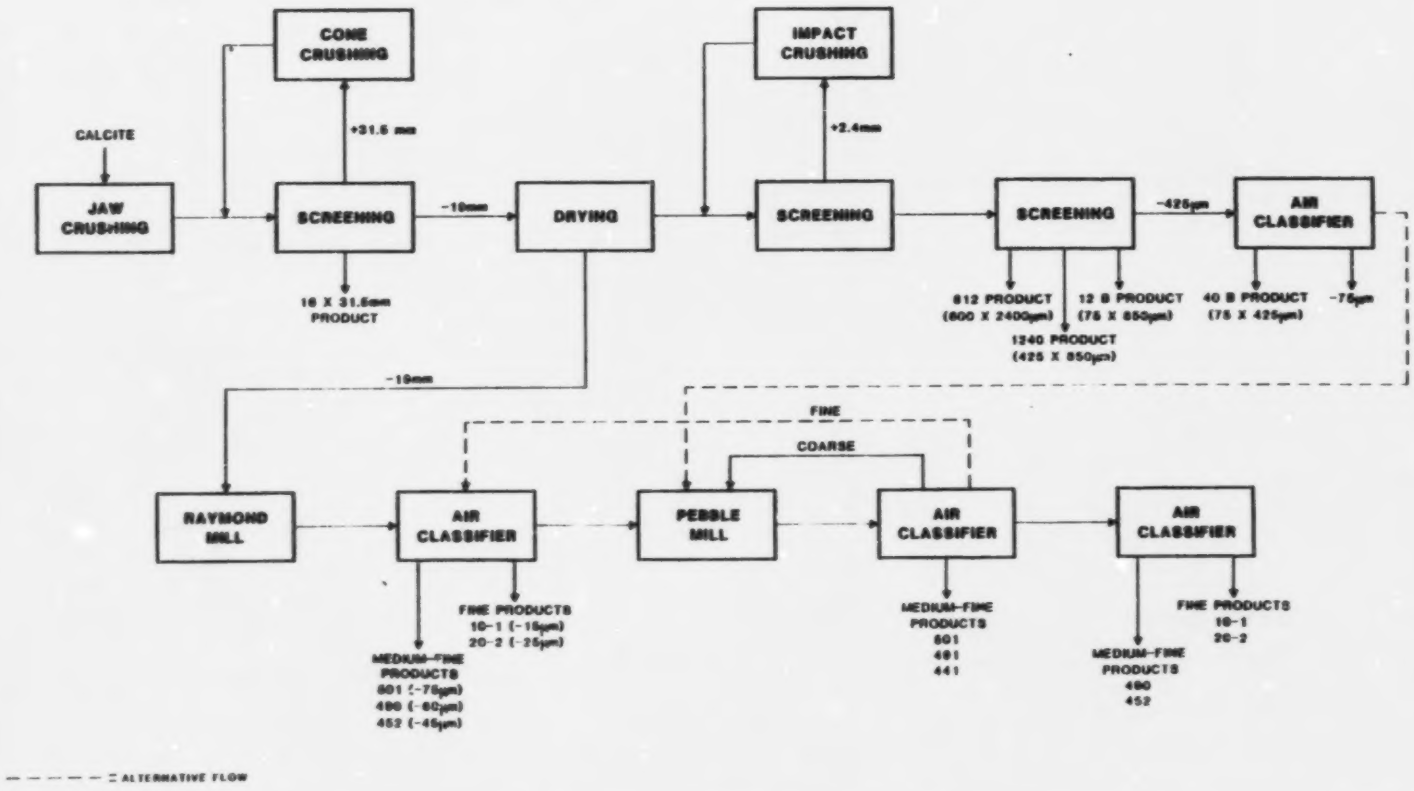
The calcite processing flowsheet of Steep Rock is shown in Figure I. Primary and secondary crushing is done at the Tatlock quarry. The rock is fed to a jaw crusher and the product screened on double-deck screens to remove the 16 by 31.5 mm saleable product and the minus 19 mm. The oversize is reduced further in two cone crushers operating in parallel and closing the circuit with the screens. Other aggregate sizes can also be produced at the quarry.

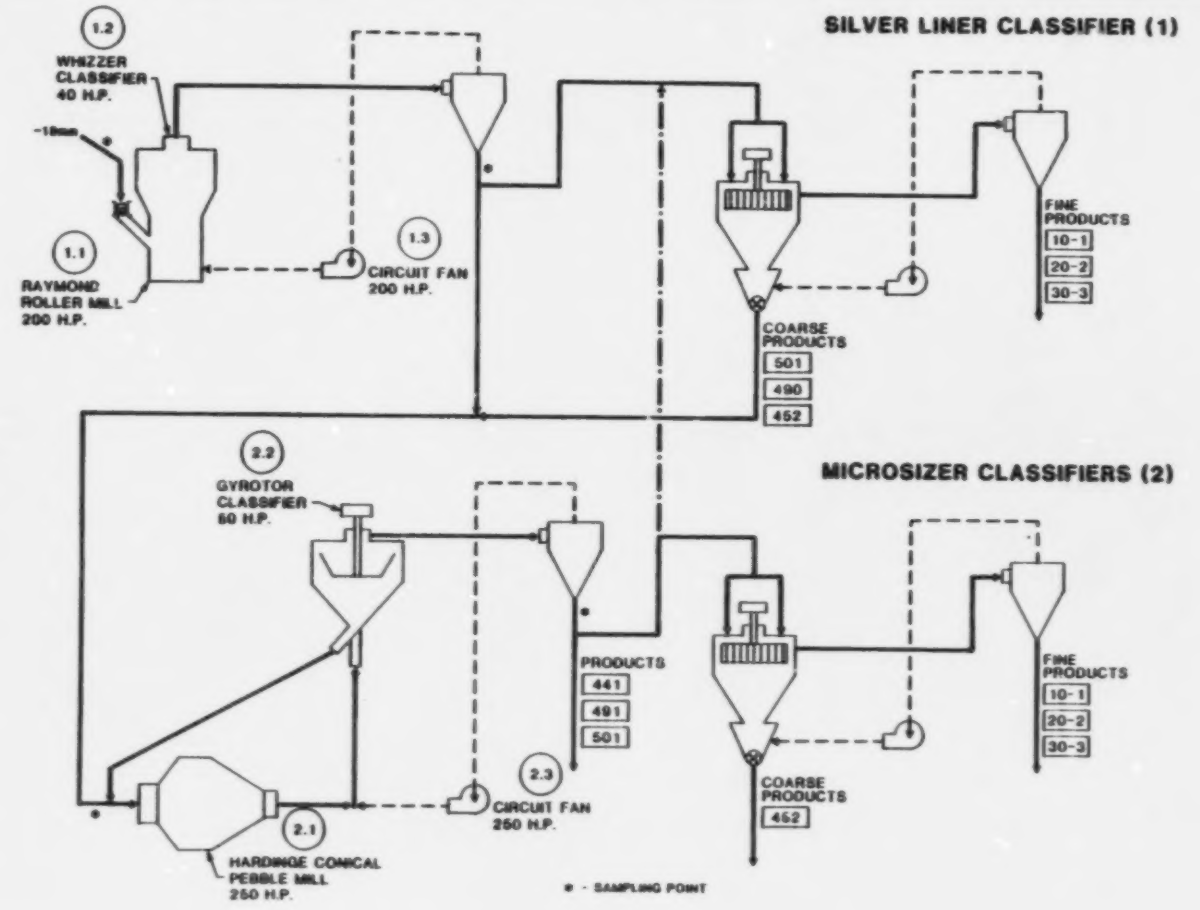
The minus 19 mm ore is trucked approximately 40 km to the Perth plant. The ore is dried, screened and air classified to produce the sand-grade products. To this end two stages of screening and one of air classification are used. The oversize of the first screen (+2.4 mm) is reduced in an impact crusher operating in closed circuit. The undersize is further screened on a double-deck screen sizing the coarser products. The undersize of the second screen is fed to an air classifier to size the finer sand-grade products. It can also be used as an alternative feed to the pebble mill.

The two grinding circuits illustrated in Figure II allow the production of the fine and medium-fine products. The standard operating practice is to feed the Raymond mill with the dried minus 19 mm ore to make the coarser 501 product (-75 μm) which serves as feed to the pebble mill. The pebble mill discharge is classified by the integrated Gyrotor air classifier which returns the coarse to the mill feed. The Gyrotor fines are further classified in two "Micro-Sizer" high efficiency air classifiers to produce the range of fine and medium-fine products. With this scheme, the production of finer products is maximized.

Figure I - CALCITE PROCESS FLOW SHEET

STEEP ROCK CALCITE PERTH, ONTARIO


CALCITE
JAW CRUSHING
SCREENING
CONE CRUSHING
+31.5 mm
16 X 31.5mm PRODUCT
-10mm
DRYING
IMPACT CRUSHING
+2.4mm
SCREENING
SCREENING
612 PRODUCT (600 X 2400µm)
1240 PRODUCT (425 X 850µm)
12 B PRODUCT (75 X 850µm)
-425µm
AIR CLASSIFIER
40 B PRODUCT (75 X 425µm)
-75µm
-10mm
RAYMOND MILL
AIR CLASSIFIER
FINE PRODUCTS 10-1 (-15µm) 20-2 (-25µm)
MEDIUM-FINE PRODUCTS 601 (-75µm) 490 (-60µm) 452 (-45µm)
FINE
COARSE
PEBBLE MILL
AIR CLASSIFIER
MEDIUM-FINE PRODUCTS 601 491 441
AIR CLASSIFIER
MEDIUM-FINE PRODUCTS 490 452
FINE PRODUCTS 10-1 20-2
= ALTERNATIVE FLOW


SILVER LINER CLASSIFIER (1)
1.2
WHIZZER CLASSIFIER 40 H.P.
-10mm
1.1
RAYMOND ROLLER MILL 200 H.P.
1.3
CIRCUIT FAN 200 H.P.
FINE PRODUCTS
10-1
20-2
30-3
COARSE PRODUCTS
501
490
452
MICROSIZER CLASSIFIERS (2)
2.2
GYROTOR CLASSIFIER 60 H.P.
PRODUCTS
441
491
501
2.3
CIRCUIT FAN 250 H.P.
2.1
HARDINGE CONICAL PEBBLE MILL 250 H.P.
FINE PRODUCTS
10-1
20-2
30-3
COARSE PRODUCTS
452
• - SAMPLING POINT

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 30-05-84
CHECKED DCS
DATE 20/09/84

FIGURE II - CALCITE GRINDING
RAYMOND & PEBBLE MILL CIRCUITS
FLOW DIAGRAM

PLANT N°

PROJECT No. 20010

Alternatively, the two grinding mills can be fed separately, thus providing greater flexibility to produce the same product range. The Gyrotor fines of the pebble mill circuit can even be conveyed to the Raymond mill air classifier for added flexibility.

The energy consumption of both grinding circuits will be hereafter examined in a typical operating condition. The study pertains only to each mill and its integrated classifier as exemplified by the material samples taken in both circuits for particle size distribution determination.

3. ENERGY CONSUMPTION

3.1 Electrical Measurements

A summary of the electrical measurements obtained on the Raymond and pebble mill circuits is presented in Table 1.

TABLE 1 - Electrical Measurements

		MOTOR HP	MEASUREMENTS		POWER DEMAND
No.	EQUIPMENT		VOLTS	AMPS	kW
1.1	Raymond Roller Mill-6669	200	560	180	140
1.2	Wizzer Classifier	40	560	20	14
1.3	Circuit Fan	200	560	105	76
2.1	Hardinge Conical Pebble Mill - 10' x 84"	250	-	-	112
2.2	Gyrotor Classifier	50	500 DC	30	15
2.3	Circuit Fan	250	-	-	112

For the Raymond mill, the amperage was read on ammeters, the voltage assumed and the power demand in kW calculated by assuming a power factor (P.F.) value of 0.8, 0.7, and 0.75 for the respective motors (1.1, 1.2, 1.3). The pebble mill and fan motors' kW demand was derived from readings on kW meters scaled 0 to 100% of nominal power; on both motors the reading observed was 60%. For the classifier, the power demand is the product of the amps reading by the assumed 500 V DC.

3.2 Flowrates

The production rates for the respective mill circuits have been estimated to be as follows:

- Raymond mill (452 Product) : 5.44 t/h
- Pebble mill (441 Product) : 5.0 t/h

3.3 Size Distributions

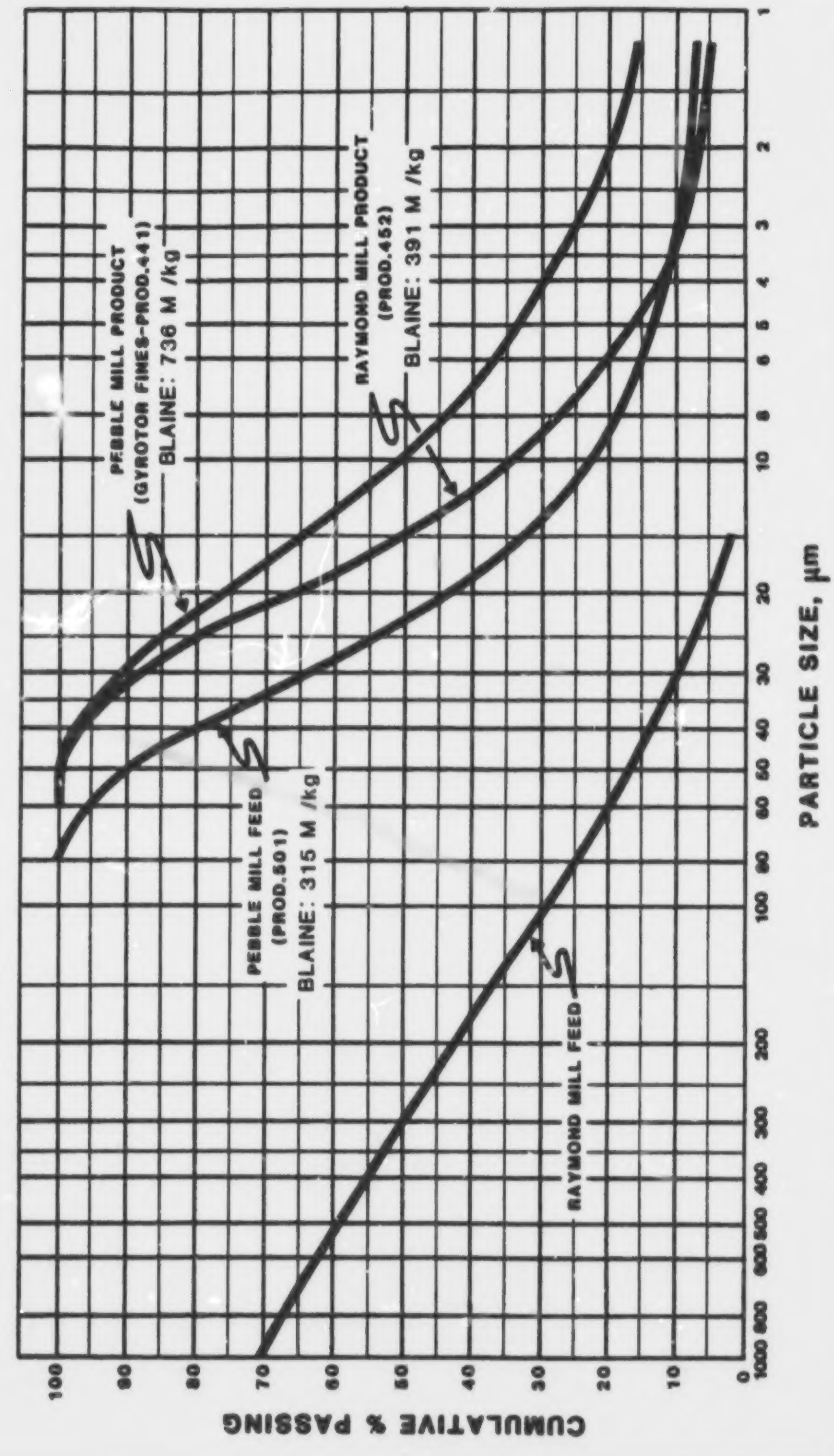
Four material samples were taken as shown on flow diagrams (Figure II) and tested for particle size distribution. The samples represented the Raymond mill feed and product, and the pebble mill feed and circuit product (in the latter case, the Gyrotor classifier fines).

The size distributions determined are shown in Figure III. The complete distribution for the Raymond mill feed sample is given in Table 2. The test results for sieve analysis, Blaine and Sedigraph can be seen in the working papers.

TABLE 2 - Raymond Mill Feed Size Distribution

µm	% Passing
19 000	100
9 500	87.8
4 750	83.5
2 360	80.3
1 180	72.9
600	62.9
300	51.0
150	38.1
75	23.5
45	16.3

Figure III - CALCITE SAMPLE SIZE DISTRIBUTIONS



The size distributions determined on these samples are in good agreement with the data in Table 3, extracted from Steep Rock products data sheets, and confirm the products that were being made at the time of plant visit. The pebble mill product with a mean particle size of 10 µm was confirmed by the plant to be representative of the 441 product.

TABLE 3 - Medium-Fine & Fine Products Physical Properties

PROPERTY	501	452	20-2	10-1
Dry Brightness (Green Filter)	90	94	95.5	96
% Retained on 75 µm sieve	2.5	-	-	-
% Retained on 45 µm sieve	20.0	1.0	0.01	0.001
Mean Particle Size, µm	22	17	7.0	4.8
Bulk Density, g/l	1100	1007	882	802
Specific Gravity	2.71	2.71	2.71	2.71
Hardness, Mohs Scale	3	3	3	3

3.4 Specific Energy Consumption

Table 4 summarizes the specific power consumption determined for both circuits and expressed as consumption for grinding alone and total consumption including auxiliaries (classifier and circuit fan).

TABLE 4 - Calcite Grinding
Specific Power Consumption

	GRINDING ONLY	GRINDING & AUXILIARIES	COMMINUTION CONSUMPTION
	kWh/tonne	kWh/tonne	%
Raymond Mill (452 Product)	25.7	42.3	61
Pebble Mill (441 Product)	22.4	47.8	47

The pebble mill specific energy consumption data shown above does not account for the energy accumulated in the mill feed, which is the 501 product produced by the Raymond mill. But the 501 product specific energy consumption can be estimated with assumed kW values derived from Table 1 and a production rate of about 10.5 t/h. In fact, the power demand of the Raymond mill circuit should be expected to decrease by about 10% when producing the 501 product. Using this assumption, total circuit power demand would be 207 kW and the 501 product specific energy consumption would approximate 20 kWh/tonne of which 12 kWh/tonne could be attributed to grinding alone. Combining these data to those of the pebble mill (Table 4) gives a cummulative total specific energy consumption of around 68 kWh/tonne of pebble mill product (441 product). The comminution consumption alone amounts to about 34 kWh/tonne and represents 50% of total consumption.

The above determined specific consumptions appear valid and reasonable when compared to other reported data in the technical literature.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Lime and limestone are frequently confused. Limestone is a general term embracing all carbonate rocks or fossils which are composed primarily of calcium carbonate ($CaCO_3$) or combinations of calcium and magnesium carbonates. It may contain varying degrees of impurities, the most common of which are silica and alumina. Lime, on the other hand, is derived from limestone through a burning process known as calcination, which expels carbon dioxide (CO_2) from the stone leaving lime (CaO, calcium oxide) according to the following formula:[1]

$$\underset{\text{limestone}}{CaCO_3} \xrightarrow{\text{heat}} \underset{\text{lime}}{CaO} + \underset{\text{carbon dioxide}}{CO_2}$$

The usual (albeit arbitrary) dividing line between limestone and any other type of rock is such that if the rock contains a total of 50% or more combined carbonates of calcium and magnesium, it is called limestone, if less, it is otherwise classified.[2]

Within the limestone group itself, there are three classes based on the relative proportions of its constituents, as shown in Table 1.

All limestone deposits contain some sandy or clayey material. "Pure" limestone is classified as having less than 5% total impurities. For commercial purposes, pure limestones are generally required. Therefore, the first classification system is considered more useful since it gives an actual percentage; while the second system, based on ratios, is viewed as more scientific because it accounts for the presence of different impurities.

TABLE 1 - Classification of Limestone[2]

CATEGORIES	PERCENTAGES	RATIOS OF CaO:MgO
Calcium Limestones*	- Calcite predominates ($CaCO_3$ crystallized in hexagonal form) - Less than 10% magnesium carbonate ($MgCO_3$)	$Cao:MgO > 10.5$
Magnesian Limestones	- Least common - Intermediate between other two classes - i.e. 10-40% $MgCO_3$	$1.76 < CaO:MgO < 10.5$
Dolomites	- 40-65% magnesium carbonate	$1.39 < CaO:MgO < 1.76$

* Includes "high calcium limestone" consisting of no greater than 3% total impurities and not more than 2% magnesium carbonate.

There are a great many different types of limestone, varying in colour, chemical composition, mineralogy, crystallinity, texture and hardness. There also exists other important calcium and magnesium bearing rocks and minerals such as gypsum, phosphate rock, serpentine and fluorspar which are not to be confused with limestone because they are not carbonate rocks (an essential characteristic of limestone).[1]

Virtually all limestones have been formed through sedimentation of calcareous matter deposited in layers or beds. Every bed is lens shaped. This lenticular character is typical of great limestone formations even though many lenses may be hundreds of kilometers across. During accumulation, limestone is a loose mass. Pressure and/or heat consolidate the minute carbonate particles into compact masses. The texture and crystalline form of the resulting rock depend on the size and shape of calcareous particles or grains that are deposited. Chalk is a soft, partly consolidated form of limestone; while marble is called a "metamorphic" limestone since it has been recrystallized through the agencies of heat or pressure, or both.[1,2]

Usually, deposits are contaminated with varying amounts of impurities which become part of the stone. The purest limestone formations are the thickest beds - often up to 30 m - although they may have strata of relatively impure stone. These beds are important sources for commercial uses which require relatively pure limestone such as in cement manufacture or as filler in the production of paper, ceramics or plastics.

Limestone is the most important and abundant of all sedimentary rocks. In virtually every country in the world, there is some occurrence of limestone, although in some countries its existence is largely negated by economic inaccessibility. Either it is lodged too deeply or intricately in the earth or is located in areas too distant from transportation and/or markets.[1] Next to sand and gravel, limestone is the greatest tonnage material produced in the U.S. and Canada, with a Canadian production of 62,337,933 tonnes in 1979.[3]

The quarrying and preparation of limestone depends on its intended use. Both mining and quarrying are used, although only about 5% of all limestone produced is mined. There are two kinds of quarries, shelf and open pit. [1,2]

For dimension stone, large, uniform blocks of stone are required. It is almost invariably worked from open pits. Channelling machines are used to make primary cuts for block separation. Once a key block is broken loose, horizontal holes can be drilled beneath adjoining blocks.The masses of stone removed may be 15-18 m long, 1.2 m wide and 3.0-3.7 m high. They are then subdivided into mill blocks of approximately 3.0 x 1.2 x 1.2 m and then hoisted to the surface. These blocks can be sold as is or further finished by cutting, carving, planing and polishing.[1,3,4]

The main use of limestone is as aggregate. For this purpose, a crushing operation is necessary. The rock is removed by blasting and then loaded by power shovels and hauled to the primary crusher by truck. Primary crushing may be done down in the quarry or at ground level. The type of primary crusher employed depends on the hardness and fracturing qualities of the stone, and particularly on the gradation that is desired in the primary product. For lime kiln feed, fluxstone or coarse aggregate, jaw or gyratory crushers are necessary. For use as cement kiln feed, hammer mills and other related impact crushers are preferred because they crush more finely than the other two types. Hammer mills are only practical with soft, nonabrasive stone.[1]

If a finer product is required, secondary crushing can be done by gyratory crusher when the top size of the feed is 150 mm or more. For smaller feed, cone crushers are preferred. Other secondary and tertiary crushing equipment include the hammer mill, rod mill and impact breakers.Hammer and rod mills produce the highest percentage of screening sizes, with approximately 50% in the 1000 μm to 300 μm range.[1]

Fine grinding is achieved with pebble mills and tube mills. For successful fine pulverization, the stone should be dried if necessary. Air separation may be used to remove the fine flour or dust as it is created making further comminution more effective.[1,4]

To produce filler grade limestone, either wet or dry processes may be employed. Wet grinding involves using ball and pebble mills or conical mills. The minute limestone is floated out of the mills in a suspension and removed after sedimentation and filtering. The material is then dried.[1]

Dry grinding is less costly than wet. Ball, pebble, roller and hammer mills are utilized. Closed circuit air separation and microsizer mills are employed for maximum fineness. Material can be produced with 99.5 to 100% passing a 45 μm sieve down to 1 μm, with an average particle size of 10 μm.

Vibratory screens of different types are used for sizing coarse products. The type, size and frequency of vibration is determined by the size gradation of the stone to be screened. More stringent quality requirements of the chemical and construction industries may necessitate washing of stone to reduce sand, clay and shale. By washing, the carbonate content can be beneficiated to 95-97% from deposits which have a high clay content.

Stone may be stored in stockpiles or surge piles uncovered on the ground. Enclosed silos or bins are used for finer grades of stone.[1,4]

The Canadian Industry

Limestone sources are available throughout Canada, although in some areas, such as the Prairies, it may be economically inaccessible because it is too deep or too far from transportation.[3,4] The large number of limestone producing operations in Canada preclude any detailed discussion here. A breakdown of production by province in 1980 and 1981 is shown in Table 2.

TABLE 2 - Canada, Production (Shipments) of Limestone, 1980 and 1981[3]

By Province	1980		1981	
	(000 t)	($000)	(000 t)	($000)
Newfoundland	675	1,778	338	1,223
Nova Scotia	216	1,942	213	2,088
New Brunswick	914	5,491	546	4,565
Quebec	22 987	76,533	23 155	83,221
Ontario	29 402	84,300	27 889	86,620
Manitoba	970	3,124	863	2,817
Alberta	193	991	271	2,001
British Columbia	2 834	10,926	2 503	10,611
Canada	58 191	185,085	55 778	193,146

As can be seen, the majority of Canadian limestone is produced in Quebec and Ontario. It can be found mostly along the St. Lawrence River Valley. British Columbia is the next largest producer but the amount is not nearly as significant. Very little limestone is imported: 3,257,316 tonnes in 1979, decreasing to 1,501,440 tonnes in 1982.

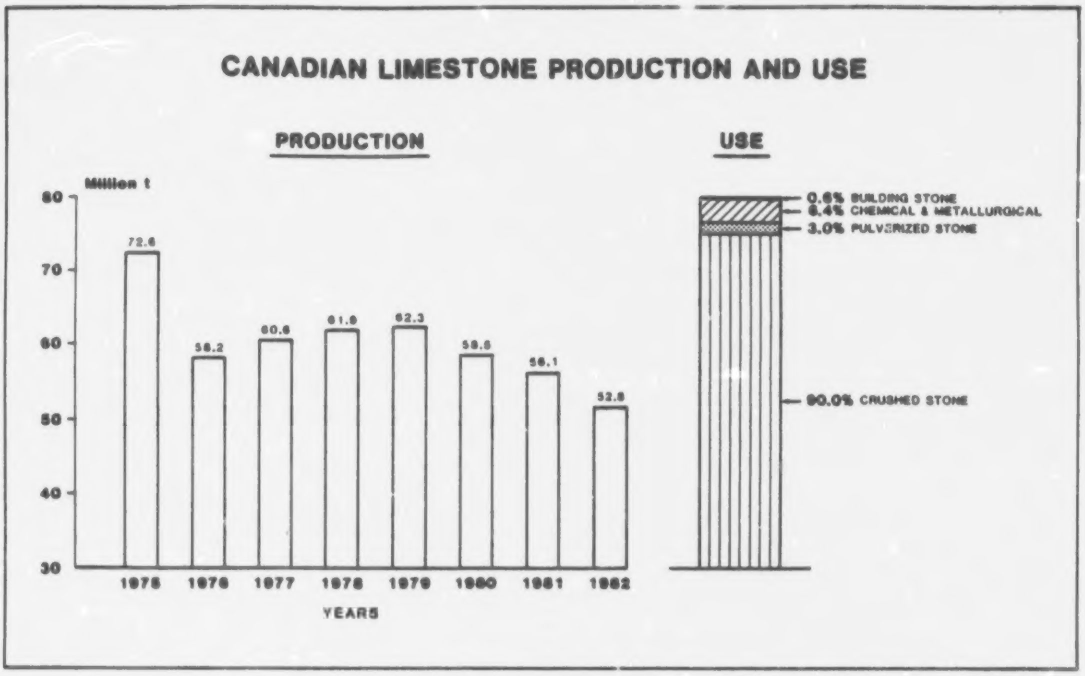
Canadian production by use can be seen in Table 3.

TABLE 3 - Canada, Shipments of Limestone by Use, 1980, 1981[3]

	1980		1981	
	(000 t)	($000)	(000 t)	($000)
Building Stone				
Rough	245	1,500	293	1,428
Monumental and ornamental	1	77	1	72
Other (flagstone, curbstone, paving blocks, etc.)	12	434	8	202
Chemical and Metallurgical				
Cement plants, foreign	1 293	2,147	1 584	2,999
Lining, open-hearth furnaces	32	90	20	71
Flux, iron and steel furnaces	1 068	3,377	757	2,779
Flux, nonferrous smelters	212	1,707	151	1,337
Glass factories	237	2,661	188	2,370
Lime kilns, foreign	306	1,102	303	1,239
Pulp and paper mills	321	2,840	345	2,886
Sugar refineries	101	394	79	378
Other chemical uses	110	1,112	148	2,277
Pulverized Stone				
Whiting substitute	32	1,513	35	1,812
Asphalt filler	53	403	34	158
Dusting, coal mines	6	159	8	167
Agricultural purposes and fertilizer plants	1 055	8,206	1 020	9,029
Other uses	573	2,749	550	466
Crushed Stone				
Artificial stone	18	50	30	123
Roofing granules	42	314	30	312
Poultry grit	52	921	24	726
Stucco dash	25	1,406	20	1,288
Rock wool	2	32	1	23
Rubble and riprap	1 048	2,190	471	1,447
Concrete aggregate	6 187	19,920	6 038	21,008
Asphalt aggregate	3 742	11,542	3 561	12,795
Road metal	19 971	59,037	18 108	58,906
Railroad ballast	992	2,322	999	3,192
Other uses	20 455	56,880	20 972	63,656
Total	58 191	185,085	55 778	193,146

The total Canadian production for 1975-1982, is shown in the following diagram.

FIGURE I - Canada, Production Volumes, 1975-82[3]
(in million tonnes, including marble)



Source: Statistics Canada; Energy, Mines and Resources Canada.

Stone is produced in direct response to the construction industry, which utilizes 95% of output, principally as crushed stone. Less than one percent of stone production is used as building stone. Chemical uses account for about 3% of stone production, the remaining 2% is consumed in pulverized form as fillers and extender materials.[3]

Market Outlook

From a tonnage standpoint, limestone's main competition is from other aggregates like sand, gravel, granite, basalt, etc., depending on cost and availability. From a usage standpoint, there are a sufficient number of overlapping uses for limestone to consider lime its most basic competition in chemical applications.[4]

In general, the outlook for limestone depends on intended use:

Dimension Stone: Traditional markets for building stone have been lost to competitive building materials such as steel and concrete. The high costs associated with quarrying, finishing, transporting and placing dimension stone in the building construction sector have contributed to the erosion of this industry.[3]

Crushed Stone: Will continue to be competitive when other sources of aggregates are scarce. It competes with gravel as railway ballast and road metal, and as aggregate in concrete and asphalt depending on cost and availability.[3]

Chemical/Metallurgical Applications & Fillers: These applications make up only a small portion of the total market for limestone, approximately 5% of total production. Limestone is used in cement and lime manufacture and as fluxing material in the metallurgical industry. The market for limestone as a filler is expanding. This is due both to changes in manufacturing processes creating a demand for $CaCO_3$, and to improved technology available to all major producers, making them able to offer a "superfine" grade of calcium carbonate fillers for uses in the manufacture of paper, plastics and paints. These superfine grades offer significant advantages over competing fillers such as excellent brightness, low abrasiveness, ease of dispersion, and in some cases, lower costs.[1,3,5]

Limestone is a rock of which the basic constituent is calcium carbonate ($CaCO_3$) or a double carbonate of calcium and magnesium. The approximate composition of several samples of limestone are shown in Table 4.

TABLE 4 - Typical Composition of Canadian Limestones

COMPONENT	LIMESTONE SAMPLE (%)			
	1	2	3	4
SiO_2	6.4	0.64	1.43	0.48
Fe_2O_3	0.58	0.18	0.72	0.51
Al_2O_3	1.68	0.21	0.66	0.27
$Ca_3(PO_4)_2$	0.07	0.15	0.04	0.02
$CaCO_3$	88.68	98.05	71.75	55.55
$MgCO_3$	1.18	0.97	25.22	42.87
Total	98.59	100.20	99.82	99.70
S	0.23	0.05	0.19	0.01
CaO	49.70	54.99	40.20	31.12
MgO	0.56	0.46	12.06	20.50
Ratio CaO:MgO	89:1	120:1	3.3:1	1.52:1
Classification	High Calcium	High Calcium	Magnesian	Dolomitic

NOTES:

1. High calcium limestone, Cape Breton, N.S.
2. High Calcium limestone, Joliette, Que.
3. Magnesian limestone, Lincoln County, Ont.
4. Dolomitic limestone, Halton County, Ont.

Source: M.F. Goudge, "Limestone of Canada"[2]

Limestones range in colour from pure white through grey and black, from blue through green, and from yellow to orange, to red and brown. These various colours are due to the presence of small quantities of pigmented impurities. Limestones free of these impurities are white.[1,4]

The texture of limestone varies considerably. Some limestones are compact, others are porous and full of cavities. All limestones are crystalline. Even chalk, which appears amorphous, is actually composed of minute crystals of $CaCO_3$ visible only under a microscope.[1,2]

Limestones also have a wide range in hardness. The amount and character of the cementing material, as well as the degree of cementation, have a great effect on hardness. The common cementing materials in limestone are silica, calcium carbonate and dolomite.[2,4] A few of the other relevant physical properties of limestone are shown in Table 5.

TABLE 5 - Properties of Limestone[1]

Specific Gravity	2.7
Hardness (Mohs scale)	3
Refractive Index	1.63 - 1.66
pH	7.8 - 8.5
Oil Absorption (cc/100gm)	12 - 30

No limestone deposit is free from impurities, the most common of which are silica, alumina, iron compounds, sulphur, alkalies, organic matter and phosphorous. They may be present in very small quantities, or constitute a large percentage of a deposit. Table 6 gives more details.

TABLE 6 - Principal Minerals & Impurities of Limestone[1,2,4]

MINERAL OR IMPURITY	PROPERTIES
Calcite $CaCO_3$	- Essential constituent - Crystals of all shapes - Effervescent when dilute acid placed on it
Dolomite $CaMg(CO_3)_2$	- Distinguish from calcite by faint or lack of reaction to cold acid - Hot acid results in brisk effervescence - Present to some extent in all limestones
Silica SiO_2	- Present in all limestones, from traces to large quantities - Forms: sand grains, chert nodules, quartz veins
Alumina Al_2O_3	- Present in combination with silica as shale or argillaceous matter (clay) - From traces to large quantities
Iron Commonly as Fe_2O_3	- Primarily in the form of oxides & sulfides - Oxides impart various colours to limestone - Ferrous iron is particularly characteristic of dolomites
Sulphur Commonly with iron as FeS_2	- Occurs principally in combination with iron as either pyrite or marcasite - H_2S (hydrogen sulphide may be occluded in the stone)
Organic Matter	- Vegetable (carbonaceous) matter deposited in the limestone as it was formed - black pigment
Others	- Phosphorus - small amounts in all Canadian deposits; Alkalies Na_2O or K_2O

QUALITY CRITERIA

Quality criteria for limestone vary with intended use (see Table 7). The chemical composition of any sample does vary from the theoretical. This is not necessarily a disadvantage. Particle characteristics may also vary depending on the raw material and methods of processing. Some minerals are prepared in a wide range of different grades, which are patterned to meet specific consumer requirements. Particle shape and surface characteristics are dependent somewhat on the fineness and method of preparation, but are mostly inherent characteristics of the rock itself. Properties such as specific gravity, refractive index, hardness and thermal properties can be modified little if at all by milling but heat treatments may alter such properties to an important extent.[1,4]

Many tests can be made at the specific request of consumers to meet particular needs such as: absorption, porosity, crystal structure, bulk density, hardness, strength, thermal conductivity, refractive index, electrical resistivity, solubility, pH, reaction with acids, etc.

The predominant chemical property of limestone is that it can be thermally decomposed (calcined) into lime. All carbonate rocks dissociate at high temperature, forming oxides of calcium and magnesium through expulsion of CO_2 gas.

TABLE 7 - Quality Criteria for Some Uses of Limestone[1,4]

USE	PROPERTIES OF INTEREST
Building Stone	- Size, shape, colour, grain - Other aesthetic qualities
Crushed Stone	- Same physical and chemical testing procedures as sand and gravel.
Aggregate	- Concrete aggregates must not contain chert (SiO_2) nodules.
Pulverized Stone	
Agricultural	- High calcium or magnesium, basic pH (7.0); used to control soil acidity.
Filler-general	- 150-45 µm particle size down to low µm range; hygroscopicity, colour, purity and surface characteristics are important; low abrasiveness.
Paper	- Brightness, low abrasiveness, ease of dispersion; coatings 1 µm, filler grades 1-2.5 µm
Plastics	- finer fillers with modified size distribution, oil absorption, low abrasiveness.
Paints	- superfine grades (as pigment extender)
Chemical/ Metallurgical	
Lime	- High calcium (95%)
Glass	- High calcium or magnesium, uniform stone, low iron, phosphorous and sulphur
Sugar	- Only high calcium stone (97%), no impurities; to precipitate impurities
Cement	- Low magnesium (2%); high silica, aluminum and calcium, some iron
Flux	- Combines with impurities to form fluid slag (in basic processes) - Low silica, high calcium - No magnesium for open hearth method - Either calcium or dolomitic limestone for blast furnaces
Others	- Uses include: manufacture of soda ash, calcium carbide, calcium nitrate, carbon dioxide, pharmaceuticals, disinfectant, dyes, rayon; neutralization of acid waste and many more.

Limestone is used extensively as a filler or extender and, where quality permits, as whiting. In such applications, both physical and chemical properties are important. Specifications vary widely but, in general, a uniform white material passing 45 µm would meet the physical requirements. Whiting is used in ceramic bodies, plastics, paper, insecticides, rubber, paints and as a filler in other commodities. In paint manufacture, the material may be used as pigment extender. Fillers are employed to modify chemical, physical, thermal or optical properties or composition. The ultimate selection of a filler for a particular application frequently depends on cost, availability and contemporary practices or traditions.[1,3,4,5]

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REFERENCES

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Volume

3

CONTENTS OF VOLUME III

Industry Reviews

Mica

Nepheline Syenite

Potash

Silica

Talc

Phase II

Establishment of Particle Size Monitoring Methodology

MICA

THE MICA INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

MAY 13 1985

MICROMEDIA

248 pp

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TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 4

  2.1 General 2
  2.2 Products Marketed 3

3. PROCESS DESCRIPTION 5 - 13

  3.1 Mica Process Flow 5
  3.2 Packaging & Shipping 12
  3.3 Air Handling System 13
  3.4 Quality Control 13

4. RESULTS & DISCUSSION 14 - 23

  4.1 Ore Crushing and Drying Circuit 14

    4.11 Power Observations 14
    4.12 Flowrates 15
    4.13 Size Distribution 15
    4.14 Grindability Testing 15
    4.15 Specific Energy Consumption 16

  4.2 Pin Mill Circuit 17

    4.21 Power Observations 17
    4.22 Flowrates 18
    4.23 Size Distribution 18
    4.24 Grindability Testing 18
    4.25 Specific Energy Consumption 19

TABLE OF CONTENTS
(cont'd)

Page No.

4.3 Fluid Energy Mill Circuit 19

    4.31 Electrical Measurements 19
    4.32 Flowrate 20
    4.33 Size Distribution 20
    4.34 Grindability Testing 20
    4.35 Specific Energy Consumption 22

4.4 Plant Air Supply 22

    4.41 Specific Power Consumption 22

4.5 Average Cummulative Power Consumption by Product 23

5. CONCLUSIONS AND RECOMMENDATIONS 24

5.1 Conclusions 24
5.2 Recommendations 24

APPENDIX - Industry Review

    1. General Information
    2. Product Characteristics
    3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Marietta Resources International Ltd.

Plant Location:

Boucherville, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the Mica industry, an appendix entitled "Industry Review" is added.

Details concerning data collection and field work, as well as other raw data or measurements, are available in the working papers.

2. COMPANY DESCRIPTION

Marietta Resources International Ltd, (MRI) is a joint venture between Société Minéralurgique Laviolette Inc., Montreal and Martin Marietta, Bethesda, Maryland. MRI is operated as part of Martin Marietta Basic Products whose headquarters are in Hunt Valley, Maryland and is the world's largest producer of mica for the plastics industry.

The company consented to the use of its Boucherville, Quebec plant to gather the necessary data required for this study.

2.1 General

Mica is a group name for some nine minerals, two of which muscovite and phlogopite are the raw materials used by the mica industry. All micas are complex hydrous silicates with varying proportions of magnesium, potassium and aluminum. Mica possesses special physical, mechanical, electrical and thermal properties. Some uses are in thermoplastics, asphalt and cement products, the electrical and electronics industry, paints, greases, mold lubrication, absorbants and in oil well drilling muds.

The original Siscoe mica deposit was discovered in 1931. The location is approximately 2 miles south west of the present mined deposit, which is just north of Parent, Quebec in Suzor Township.

In 1960, Société Minéralurgique Laviolette Inc., acquired ownership of the original mine and in the same year discovered the present Bedard deposit.

There are over 30 million tonnes of 85-95% pure ore in the Bedard deposit; about double the purity of the original Siscoe mine.

In 1972, a decision was made to build a pilot plant in the Pointe St-Charles district of Montreal. This became operational in 1973, and after several modifications and expansions, a decision to build a full-scale production plant was made.

In 1976, construction of the plant began and in late January 1977, it was commissioned, but with limited production.

In 1978, the production increased considerably and subsequently doubled in 1979 to about 11,000 tonnes per year. It has remained near to this level since.

The plant processes about 15,000 tonnes of ore annually, depending on the product mix.

Geographical distribution of sales are:

25%	Domestic
60%	United States
15%	South America, Europe and Japan

2.2 Products Marketed

MRI produces three main types of mica products: Z, S and FE. From these, about 20 different classifications, based primarily on purity, degree of fineness and aspect ratio,* are marketed.

* Aspect Ratio: the average diameter of a flake divided by its thickness.

2. COMPANY DESCRIPTION (cont'd)

From 1978 to 1983, the demand has changed from coarse "Z" to fine "FE" products as the need for filler material increased.

Shipments are either bulk or bagged, which are palleted and wrapped. During bulk loading a sample is taken from each ton and during bagging at every 20th bag. Size distribution, bulk density and sieve analysis tests are run to monitor the quality of the product.

3. PROCESS DESCRIPTION

3.1 Mica Process Flow

An overview of the MRI process is shown on the flow sheet, Figure I.

Comminution in the true sense is a limited operation except in the primary crushing stage, which receives the mined ore from the stockpile. Elsewhere, the impact crusher and pin mill are used to delaminate the flakes.

The main processing operations are crushing, drying, screening and sifting. The three broad classes of products result from sequential phases of the process.

"Z" Products

High-purity ore from the Bedard mine is locally crushed to a maximum 23 cm diameter, then trucked to the railhead at McCarthy, Quebec where it is shipped to the Boucherville plant and stockpiled.

The ore is retrieved from the stockpile by front-end loader and is dumped onto a belt conveyor and transported to the primary jaw crusher, and reduced to a maximum diameter of 5 cm. The process is outlined on the flow sheet, Figure II, and the equipment in Table 1.

The crushed ore is transported via conveyor and bucket elevator to a feed bin which then discharges it into a rotary dryer, where the moisture content is reduced from about 6% to between 0.2 and 0.5%.

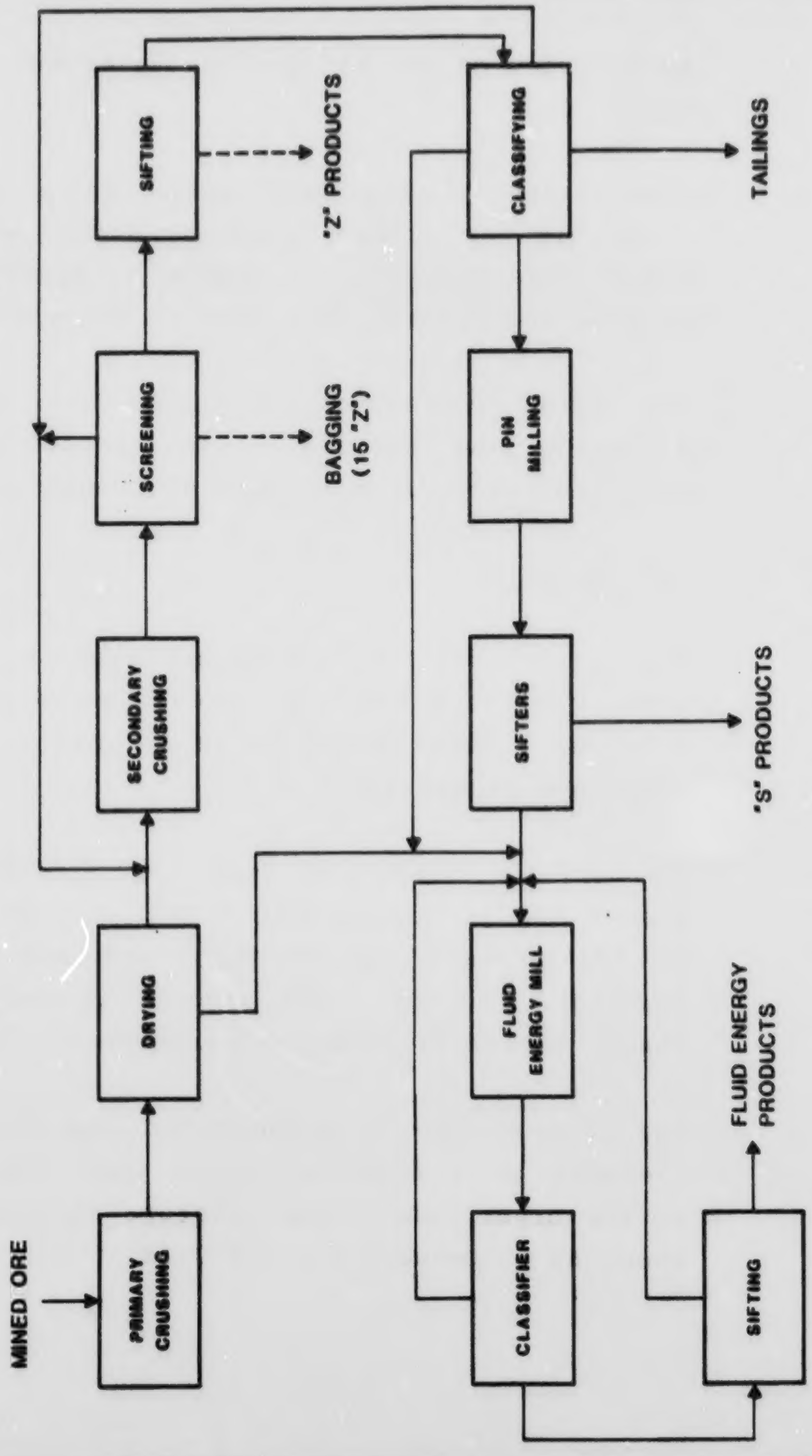
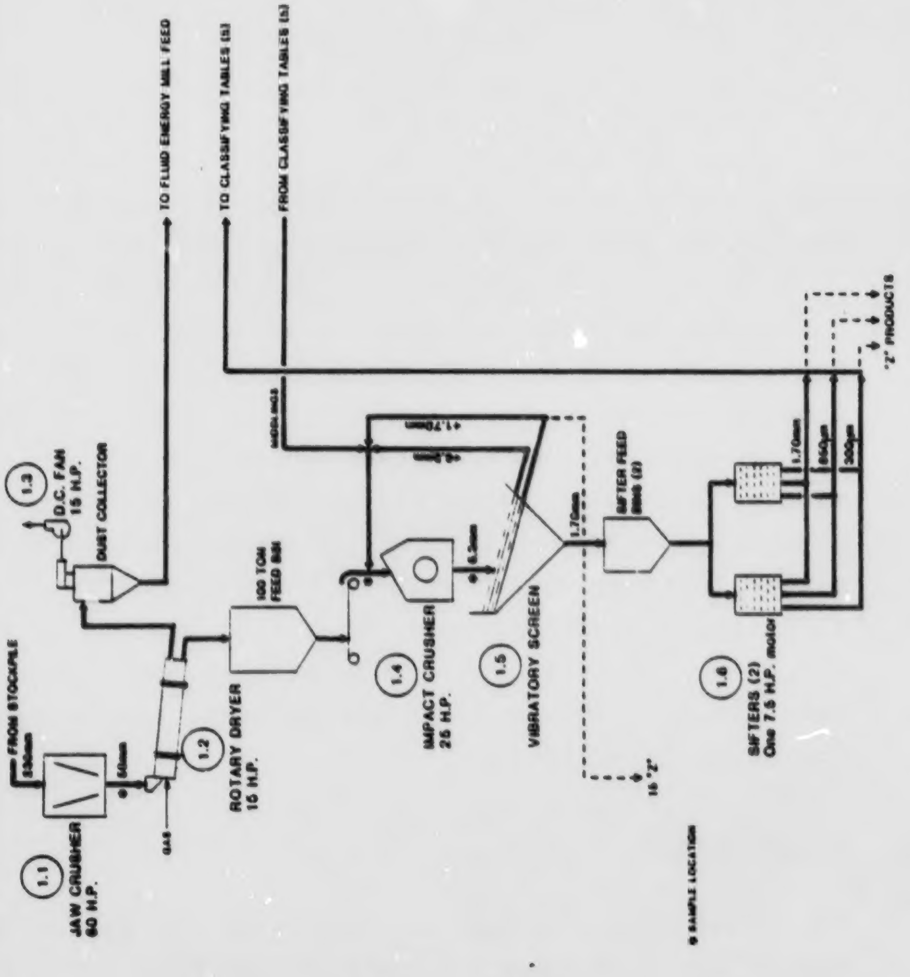

MINED ORE
PRIMARY CRUSHING
DRYING
SECONDARY CRUSHING
SCREENING
SIFTING
BAGGING (15 "Z")
"Z" PRODUCTS
CLASSIFYING
TAILINGS
PIN MILLING
SIFTERS
"S" PRODUCTS
FLUID ENERGY MILL
CLASSIFIER
SIFTING
FLUID ENERGY PRODUCTS

Figure I - MICA PROCESS FLOW SHEET
MARIETTA RESOURCES LTD., BOUCHERVILLE, QUEBEC


FROM STOCKPILE
330mm
1.1
JAW CRUSHER
60 H.P.
50mm
GAS
1.2
ROTARY DRYER
15 H.P.
1.3
D.C. FAN
15 H.P.
DUST COLLECTOR
TO FLUID ENERGY MILL FEED
TO CLASSIFYING TABLES (5)
FROM CLASSIFYING TABLES (5)
MIDDLINGS
100 TON
FEED BIN
1.4
IMPACT CRUSHER
25 H.P.
6.3mm
+6.3mm
+1.70mm
1.5
VIBRATORY SCREEN
1.70mm
SIFTER FEED
BINS (2)
1.6
SIFTERS (2)
One 7.5 H.P. motor
1.70mm
850µm
300µm
"Z" PRODUCTS
16 "Z"
⊕ SAMPLE LOCATION

CANADA CEMENT LAFARGE LTD.
MONTREAL

PLANT: MARIETTA RESOURCES LTD.
BOUCHERVILLE, QUEBEC

FIGURE II
CRUSHING CIRCUIT

DRAWN GFJ
DATE 20/01/84
CHECKED DCS
DATE 20/08/84

PROJECT No. 20010

TABLE 1 - Crushing - Equipment List

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR*	
		HP	AMPS
1.1	Jaw Crusher	60	59
1.2	Dryer	15	15
1.3	Dryer Dust Collector Fan	15	14.5
1.4	Impact Crusher	25	24
1.5	Vibratory Screen (Air Operated)	-	-
1.6	'Z' Product Sifters	7.5	7.8

* All motors are 550 volts.

The fines in the dryer are air-swept to the dust collector and become part of the fluid energy (FE) mill feed.

The remaining dried material is moved by belt conveyor and bucket elevator to a 91 tonne bin which feeds an impact crusher. The crusher discharge (6.3 mm) is fed to an air-operated vibratory screen where the oversize and the middle cut are recirculated back to the secondary crusher. In some instances the impure 6.3 mm middle size material is bagged and sold to a limited market. The fine material (1.7 mm) is sent to a feed bin which feeds the first set of sifters. The sifters can produce three products 20Z, 40Z, 60Z, or the material can continue on to the classifying tables.

"S" Products

The classifying tables are designed to retain the mica flakes and eliminate the foreign material. The fines are drawn off to a dust collector. The accepts are sent to a pin mill, which continues to "sheet" the ore. The discharge is air swept into a dust collector, whose discharge passes on to a feed bin supplying three sets of sifters.

The sifter products feed several product bins of 150S, 20S, 40S, 60S and 150 µm material.

As shown in Figure III, a composite of 40S, 60S and 150 µm material, together with the dust collector discharge from the dryer and classifying tables, becomes the feed to the Fluid Energy mill. The equipment details are shown in Table 2.

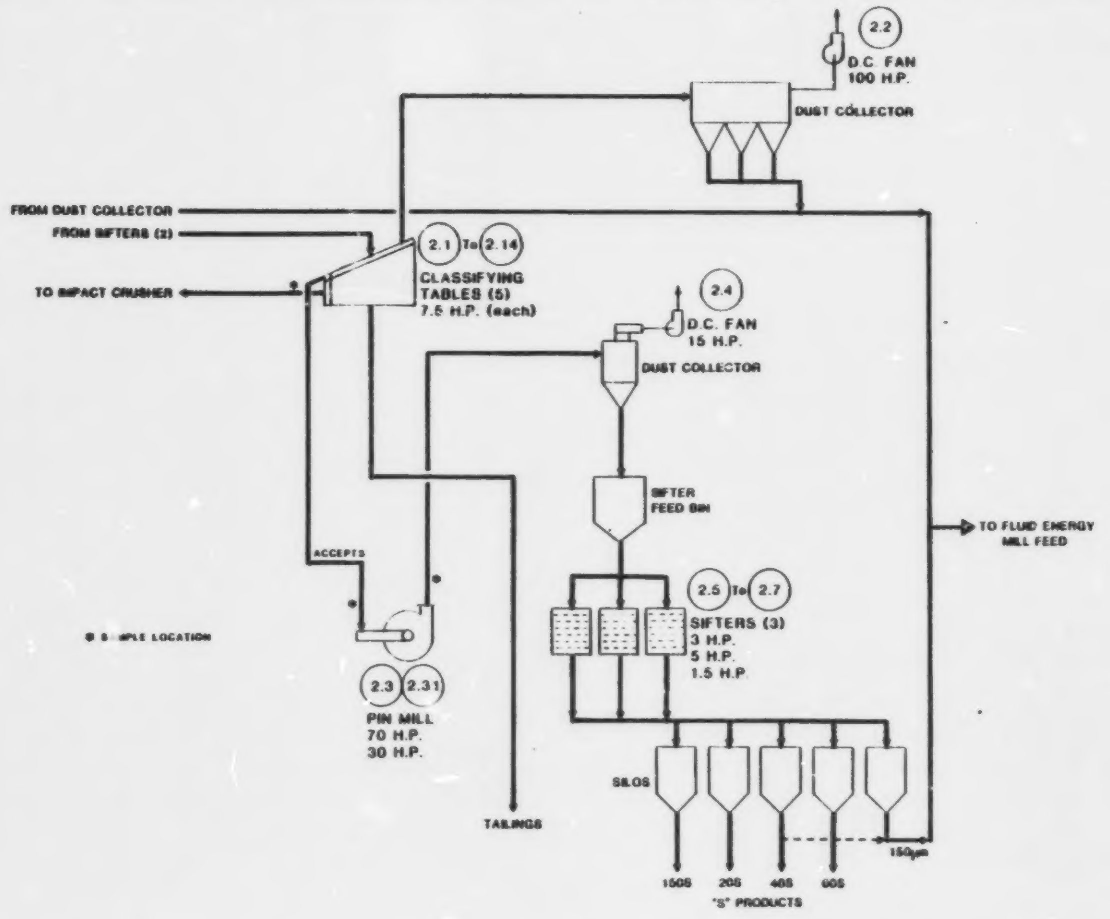
TABLE 2 - "S" Product - Equipment List

	EQUIPMENT	MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
2.1	Classifying Table #1	7.5	7.8
2.11	" " " #2	7.5	7.8
2.12	" " " #3	7.5	7.8
2.13	" " " #4	7.5	7.8
2.14	" " " #5	7.5	7.8
2.2	Classifying Table D.C. Fan	100	96
2.3	Pin Mill (Same Direction)	75	70
2.31	" " (" ")	30	29.2
2.3	Pin Mill (Opposite Direction)	75	70
2.31	" " (" ")	30	29.2
2.4	Pin Mill D.C. Fan	15	13.5
2.5	'S' Product Sifters #3	3	4.7
2.6	'S' Product Sifters #6	5	5.2
2.7	'S' Product Sifters - 150S	1.5	2.3

* Motors are 550 volts.

"FE" Fluid Energy Products

The selected "S" product and dust from the circuit dust collector are conveyed to the fluid energy silo; whose discharge is then transported by screw conveyor to a feed box from which dual screw conveyors feed the fluid energy mill. As detailed in the circuit diagram, Figure IV, and in the equipment list, Table 3, the material is classified and the oversize is recirculated back to the feed box with the fines being air swept to the fluid energy mill dust collector.


2.2
D.C. FAN
100 H.P.
DUST COLLECTOR
FROM DUST COLLECTOR
FROM SIFTERS (2)
TO IMPACT CRUSHER
2.1 To 2.14
CLASSIFYING
TABLES (5)
7.5 H.P. (each)
2.4
D.C. FAN
15 H.P.
DUST COLLECTOR
SIFTER
FEED BIN
TO FLUID ENERGY
MILL FEED
ACCEPTS
SAMPLE LOCATION
2.5 To 2.7
SIFTERS (3)
3 H.P.
5 H.P.
1.5 H.P.
2.3 2.31
PIN MILL
70 H.P.
30 H.P.
SILOS
TAILINGS
150µm
150S
20S
40S
60S
"S" PRODUCTS

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN GFJ
DATE 20/01/84
CHECKED DCS
DATE 20/09/84

FIGURE III
PIN MILLING CIRCUIT

PLANT No MARIETTA RESOURCES LTD
BOUCHERVILLE, QUEBEC

PROJECT No. 20010

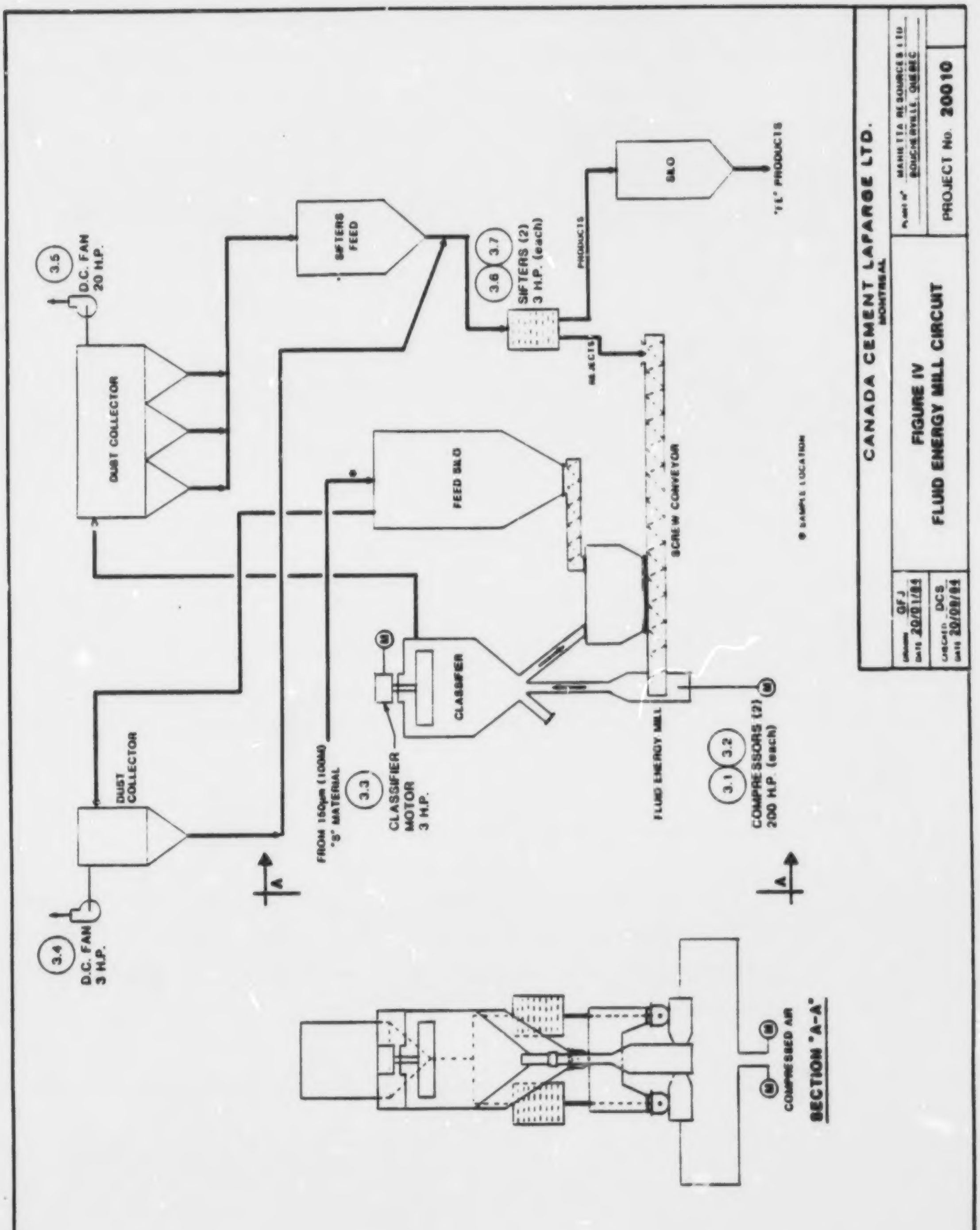


FIGURE IV
FLUID ENERGY MILL CIRCUIT

CANADA CEMENT LAFARGE LTD.
MONTREAL
PLANT AT MARIETTA RESOURCES LTD
BOUCHERVILLE, QUEBEC
PROJECT No. 20010
DRAWN GFJ
DATE 20/01/84
CHECKED DCS
DATE 20/09/84
3.5 D.C. FAN 20 H.P.
SIFTERS FEED
SILO
"FL" PRODUCTS
PRODUCTS
3.6 3.7 SIFTERS (2) 3 H.P. (each)
REJECTS
DUST COLLECTOR
FEED SILO
SCREW CONVEYOR
SAMPLE LOCATION
CLASSIFIER
FLUID ENERGY MILL
FROM 150µm (100M) "S" MATERIAL
3.3 CLASSIFIER MOTOR 3 H.P.
3.1 3.2 COMPRESSORS (2) 200 H.P. (each)
DUST COLLECTOR
3.4 D.C. FAN 3 H.P.
A
A
M
M
M
COMPRESSED AIR
SECTION "A-A"

The feed silo dust collector discharge and the classifier dust collector discharge form the fluid energy sifter feed. The oversize from the sifters is recirculated back to the fluid energy mill and the fine product is delivered by screw conveyor to the FE product silos.

TABLE 3 - "FE" Product Equipment List

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR* HP	MOTOR* AMPS
3.1	Fluid Energy Mill Compressor #1	200	184
3.2	Fluid Energy Mill Compressor #2	200	184
3.3	Classifier Motor	3	3.5
3.4	Fluid Energy Mill Small D.C. Fan	3	3.6
3.5	Fluid Energy Mill Large D.C. Fan	20	20
3.6	Fluid Energy Sifter #9	3	3.5
3.7	Fluid Energy Sifter #10	3	3.2

* Motors are 550 volts.

3.2 Packaging and Shipping

From the product bins, various blends are bagged at the main bagging station or at local units. The bags are palletized and wrapped for security and protection against moisture.

Bulk shipments are made in special pneumatic tank trucks.

3.3 Air Handling System

An oversized air handling system is required, due to the amount of fine product involved. Air flow is caused by the dust collector exhaust fan, aided by the fluid energy mill compressed air system.

3.4 Quality Control

As a general rule, 1 lb samples are taken from every 20th bag or from each tonne of bulk product. Bulk dry density and wet screen tests are run. Several other tests, such as colour, absorption, chemical analysis, etc., may be required for specific applications.

4. RESULTS AND DISCUSSION

The analysis of the electrical data obtained during the study will, for clarification, be grouped according to circuit operation.

4.1 Ore Crushing and Drying Circuit

4.11 Power Observations

A summary of the power observations on the crushing circuits is shown in Table 4.

TABLE 4 - Ore Crushing and Drying Circuit Power Measurements

No.	EQUIPMENT	MOTOR HP	POWER USAGE AVERAGE kW
1.1	Jaw Crusher	60	7
1.2	Drying	15	4
1.3	Dryer D.C. Fan	15	9
1.4	Impact Crusher	25	7
1.5	Vibratory Screen (Air Operated)	-	-
1.6	'Z' Product Sifter	7.5	1

The power factor of the primary crusher fluctuated substantially under full-load and no-load conditions. An average was derived and used for the power requirement calculation. However, the impact crusher operated consistently at a high power factor, as illustrated in Table 5.

TABLE 5 - Crusher Power Level

CRUSHER	kW DEMAND LEVEL (%)	
	Low	High
Jaw	30	99
Impact	99.9	99.9

4.12 Flowrates

Plant records for the year 1983 indicate that the average flowrate from the stockpile into the mill is 6.6 tonnes per hour (6.0 tonnes per hour dry).

4.13 Size Distribution

Average size distributions obtained from plant records for the material at the two crushers are as shown in Table 6. Nominal feed size to the primary crusher is 228.6 mm.

TABLE 6 - Size Distribution - % Passing

SIZE	PRIMARY CRUSHER	SECONDARY CRUSHER		PRIMARY SCREEN	
mm	Discharge	Feed	Discharge	Oversize	Undersize
37.50	70	73			
6.30	30	38			
3.35			80	20	
2.36					100
2.00	10	16		Trace	
0.85			35		40
0.30			13		15

4.14 Grindability Testing

A 15Z coarse product sample (containing gangue material) was sent to Canada Cement Lafarge Research and Development Laboratory to run grindability tests, by both the Hardgrove and Bond test methods and a sieve analysis.

The Hardgrove Index was determined to be 16, indicating that mica is a very hard material.

The Bond Work Index could not be measured experimentally due to the flaky nature of the mineral. It was calculated from the Hardgrove Grindabilty Index to be 34.88 kWh/t.

The sieve analysis of the sample provided the results indicated in Table 7.

TABLE 7 - 15Z Sieve Analysis - % Passing

SIZE	% PASSING
4.75 mm	84.1
2.36	23.5
1.18	1.7
600 µm	0.7
300	0.5
150	0.3

4.15 Specific Energy Consumption

To determine the amount of specific energy being used for the circuit operation, the power in kW is divided by the estimated flowrate. In all cases average figures were used.

The results for the crushing circuit are shown in Table 8.

TABLE 8 - Ore Crushing and Drying Circuit
Specific Power Consumption

Flowrate 6.0 tonne/hour Dry Ore

	kWh/tonne	%
Comminution	2.3	50
Auxiliaries	2.3	50
Total	4.6	100

A breakdown of the auxiliaries indicates that drying requires an electrical power demand nearly equal to that required for comminution, as shown in Table 9.

TABLE 9 - Ore Crushing and Drying Circuit
Power Demand Distribution

Demand Distribution	%
Drying	45
Sifting	4

4.2 Pin Mill Circuit

4.21 Power Observations

A summary of the electrical measurement calculations are shown in Table 10.

TABLE 10 - Delamination Ciruit
Power Measurement Calculation

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATION
			Average kW
2.1	Classifying Table 1	7.5	4
2.11	Classifying Table 2	7.5	4
2.12	Classifying Table 3	7.5	4
2.13	Classifying Table 4	7.5	4
2.14	Classifying Table 5	7.5	4
2.2	Classifying Tables D.C. Fan	100	45
2.3	Pin Mill (Same Direction)	70	17
2.31	Pin Mill (Same Direction)	30	3
2.3	Pin Mill (Opposite Direction)	70	26
2.31	Pin Mill (Opposite Direction)	30	6
2.4	Pin Mill D.C. Fan	15	7
2.5	Sifters #3	3	2
2.6	Sifters #6	5	2
2.7	Sifters - 150S	1.5	-

The calculations indicate that the equipment was operating at an average level of power consumption.

4.22 Flowrates

The average flowrate of 1.32 tonnes/hour of beneficiated feed to the pin mill, was determined from actual operational data provided from plant records.

4.23 Size Distribution

There is only one crushing operation involved in this circuit. It takes place when the pin mill rotors operate in opposite directions.

A comparison of the sieve analysis of the plant provided feed sample and a tested 20S product sample, are shown in Table 11.

TABLE 11 - Pin Mill Feed and 'S' Product Size Distribution - % Passing

SIZE	FEED	% PASSING '20S'
2.00 mm	82	100
1.18		33.3
600 µm		2.4
425	19	
300		1.6
150		1.0
75	1	

4.24 Grindability Testing

A sample of 20S product was taken for the Hardgrove and Bond Index test methods and for a sieve analysis.

The testing results were similar to the 15Z sample. The Hardgrove Index was 13 and the calculated Bond Index was 42 kWh/Ton.

The sieve analysis summarizes the degree of size reduction involved in the 'S' product stage.

4.25 Specific Energy Consumption

Table 12 provides the specific power consumption for the pin mill circuit.

The operation of the pin mill encompasses both crushing and delamination operations. When delamination occurs, power consumption for the auxiliaries remains unchanged but mill power consumption drops by 37%.

TABLE 12 - Pin Mill Circuit
Specific Power Consumption

	kWh/tonne	%
Comminution	24.5	31
Auxiliaries	55.1	69
Total Consumption	79.6	100
Delamination	15.4	21.8
Auxiliaries	55.1	78.2
Total Consumption	70.5	100.0

Dust collection for the circuit uses significantly more power than comminution or delamination.

4.3 Fluid Energy Mill Circuit

4.31 Electrical Measurements

A summary of the electrical measurements for the fluid energy mill circuit are shown in Table 13.

TABLE 13 - Fluid Energy Mill Circuit - Power Demand

No.	EQUIPMENT	MOTOR HP	POWER DEMAND
			AVERAGE kW
3.1	Fluid Energy Mill Compressor #1	200	148
3.2	Fluid Energy Mill Compressor #2	200	173
3.3	Classifier Motor	3	1
3.4	Fluid Energy Mill Small D.C. Fan	3	3
3.5	Fluid Energy Mill Large D.C. Fan	20	6
3.6	Fluid Energy Sifter #9	3	1
3.7	Fluid Energy Sifter #10	3	1

4.32 Flowrate

The 0.68 tonne/hour flowrate for this circuit is based on data obtained from plant records.

4.33 Size Distribution

Feed to the fluid energy mill is mainly 150S material as shown in Table 14.

TABLE 14 - Fluid Energy Mill Size Distribution

SIZE (µm)	% PASSING
250	96
150	45-60
75	50-65
- 75	0-10

The fluid energy mill produces very fine material ranging from 40% to plus 92% passing 45 µm.

A 325S sample was analysed by Sedigraph as shown in Figure V.

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION **MICA SUZORITE 325-S (FE)**

DATE **March 27, 1984**

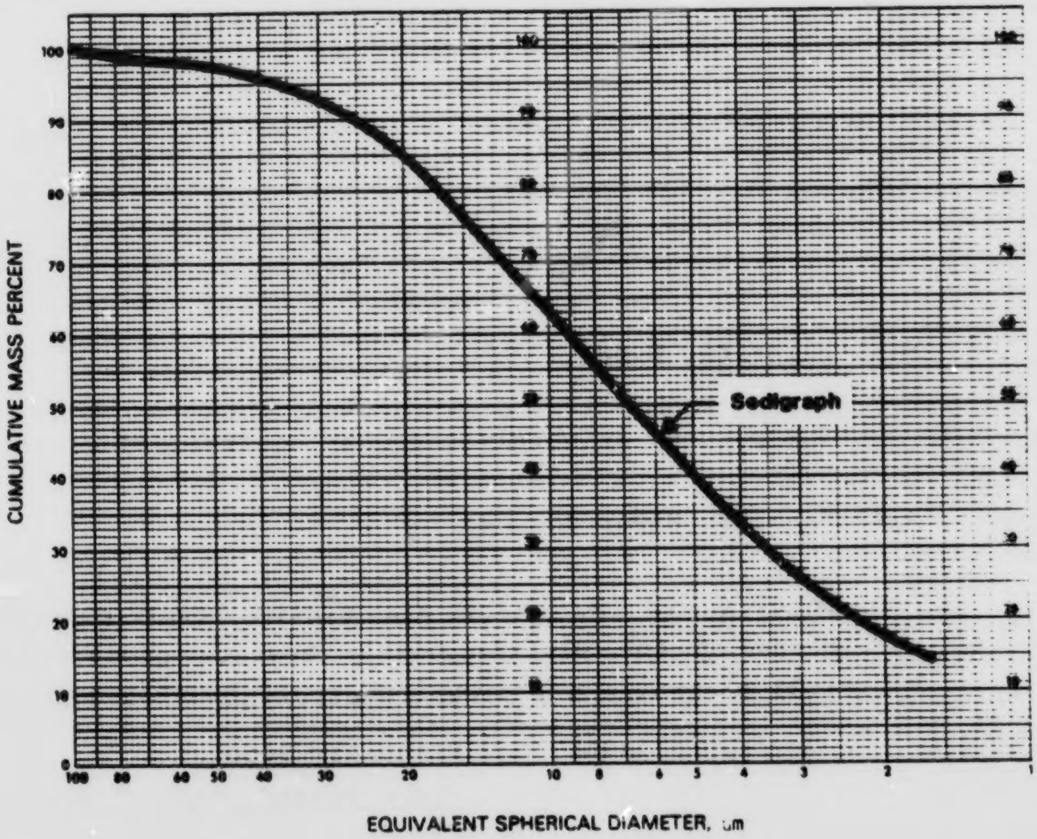
Density ______ g/cc LIQUID ______ Density ______ g/cc Viscosity ______ cp

BY **W. Budd**

Preparation **100 seconds Sampling time**

TEMPERATURE ______ °C

RATE ______ START DIA ______ µm



4.34 Grindability Testing

Due to the characteristics of the mineral, no tests were run.

4.35 Specific Energy Consumption

Table 15 provides a clear understanding of how energy intensive the power demand requirement is when fine products are produced.

TABLE 15 - Fluid Energy Mill
Specific Power Consumption

	kWh/tonne	%
Comminution	471	96.5
Auxiliaries	17	3.5
Total	488	100

4.4 Plant Air Supply

The purpose is mainly for dust control and cleaning.

4.41 Specific Power Consumption

Determining the plant air system power consumption was based on the plant's hourly average production rate of 1.33 tonnes, and a power requirement of 62.2 kWh/tonne.

TABLE 16 - Plant Air Supply
Power Demand Calculations

No.	EQUIPMENT	MOTOR HP	POWER DEMAND AVERAGE kW
1	Plant/D.C. Air Compressor	100	40.2
2	Plant/D.C. Air Compressor	100	42.5

4.5 Average Cumulative Power Consumption by Product

For an overall comparison of power requirements, Table 17 was developed. It provides a clear understanding of how product fineness, beneficiation and dust collection increases the power requirements.

TABLE 17 - Average Cumulative Power Consumption

CIRCUIT	kWh/tonne		Comparison % Comminution
	Comminution	Comminution & Auxiliaries	
Ore Crushing & Drying	2	5	40
Pin Mill	27	85	32
Fluid Energy Mill	498	573	87
Total	527	663	79

From the table, total comminution is 79% of direct plant operations. However, if plant air is included, the comparison percentage is reduced to 73%. Still considerable, since production levels in the Fluid Energy circuit are increasing.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As a result of the study, we can conclude that the requirement for high aspect ratio and high fines below 95 µm is energy intensive.

Also, it was observed that dust collection and plant air systems are significant power consumers. Comparatively, the sifters (the equipment responsible for producing product) are low power consumers.

It is probable that significant decreases in power utilization could be achieved by using another type of fine grinding mill, better classification of fine product and by increasing production volumes through plant expansion.

Mica is extremely hard and abrasive, requiring special protective materials.

5.2 Recommendations

An effort should be made to test other types of mills, materials and classifiers which could probably reduce the cumulative product power consumption for mediocre fine and fine products.

Also, due to the low bulk density of the beneficiated mica, try locating fine grinding units near market centers.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and Its Processing

Mica is the general name for a group of some nine different minerals, two of which, muscovite and phlogopite, are the two used by the mica industry as its raw material. All mica minerals are complex hydrous silicates with varying proportions of magnesium, potassium and aluminum, usually some iron and fluorine, and sometimes sodium, lithium, titanium, barium and manganese. Mica minerals possess some very special physical, mechanical, electrical and thermal properties. As a result, these minerals are used extensively in various fields for industrial and commercial applications.[1,2]

Mica in the form of large sheets or flakes has been an important electrical insulator because of its cleavability, flexibility and high dielectric strength. Before the invention of transistors and solid state devices, mica film was used in vacuum tubes. Currently, mica film is used in capacitors electric motors and generators. The high heat resistance of mica flakes has also prompted its use as a thermal insulator in electric appliances. Because of its special electrical and thermal properties, mica has been recognized as a strategic mineral in several industrialized countries.[1]

Mica is found widely throughout the world, (see map, page 3) but concentrations large enough and sufficiently well crystallized for processing into the valuable block mica are comparatively scarce.

Prior to 1900, the United States was the principal world producer of sheet mica. Deposits were mined in New Hampshire, North Carolina, Maine, Virginia, and South Dakota.

Mica was first produced in 1810 at the Ruggles mine in New Hampshire. Until the development of the electrical industry, specifications for mica were comparatively moderate, since its chief use then was for stove windows. The colloquial term for this product was "isinglass". As the demand for isinglass dwindled and the demand by the electrical industry grew, intensive development of mica deposits yielding higher grade sheets took place in various parts of the world. India, Brazil and Africa became important sources.[2] However, the U.S. remains the world's largest producer.

TABLE 1 - World Production
All forms (ground, flake & sheet)

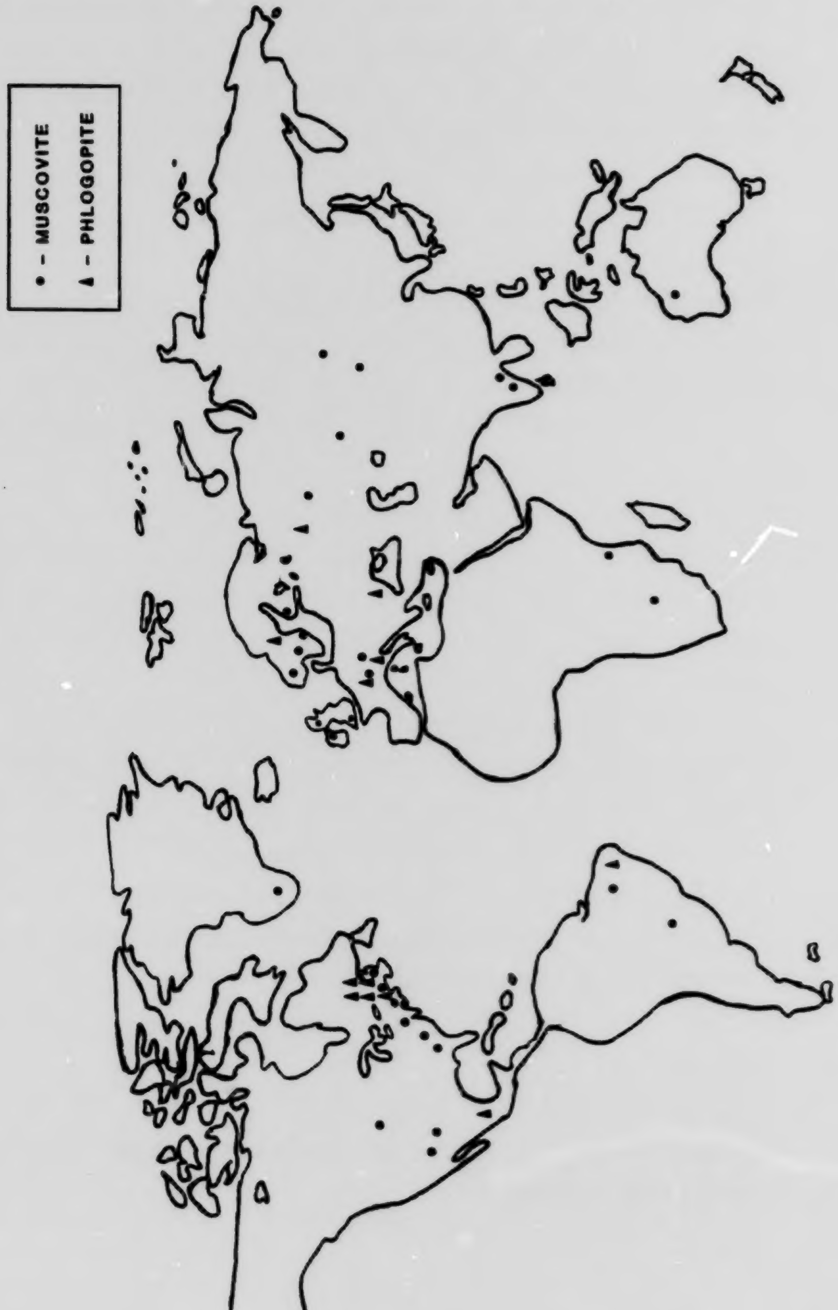
(tonnes)

COUNTRY	1981 (Preliminary)	1982 (Estimated)	%
United States	226,800	183,250	63
U.S.S.R.	47,170	48,080	16
India	40,220	21,550	7
Canada	11,122	10,079	4
Republic of Korea	10,000	9,980	3
France	6,800	6,490	2
Spain	5,000	3,300	1
Brazil	4,500	4,500	2
Other	10,120	6,160	2
TOTAL	361,742	293,399	100

Source: U.S. Bureau of Mines

Because of the erratic nature of sheet mica deposits and the impossibility of predicting the profitability of a deposit, block or sheet mica is still mined by fairly primitive methods. It is general practice to "follow the vein", which means a much higher cost per tonne of rock removed, but a lower cost per tonne of mica recovered.

MAJOR WORLD DEPOSITS OF MICA


● – MUSCOVITE
▲ – PHLOGOPITE

Mica that is of poor quality for working into blocks, but is larger in size or has better crystallization than scrap, becomes the raw material for mica splittings which are extremely thin sheets or flakes (0.003 cm). In the United States and Canada, mica of this quality is marketed as "punch" or "washer" mica, where the material is punched into plain washers and simple insulating shapes for use in applications where some imperfections are not detrimental.

Mica plate is fabricated where mica is required in larger sizes than normally found in nature. It is produced by combining mica splittings with binders such as shellac, glyptol, silicone resins etc., and curing under heat and pressure.[2,5]

Dry-ground mica is produced principally by hammer mills, and is marketed in various sizes. A coarser size is used in oil well drilling fluids, while a finer size is used as a filler in gypsum board and plastic paints. There are numerous minor uses.

Wet-ground mica is produced by a batch process in mullers. After grinding, impurities (mostly quartz and feldspar) are settled out and organic impurities are floated off. After a drying operation, the mica is screened. Wet-ground mica is produced in considerably finer sizes than dry-ground (95 µm & 125 µm). Wet-ground products are being used increasingly as a filler in paint, plastics and especially for electrical insulation.[2,5]

Ground mica is made to consumer size specifications and is preferred color-free.

Sheet mica is classified into different sizes known as grades. The grade of any piece of mica is determined by the area of the largest sound rectangle which can be obtained from the original irregularly shaped piece. Quality classification is based on visual judgement (resulting in considerable variation from one producer to the next). The judgement is based on translucence, color, stains, and the presence of cracks or other physical imperfections.[2]

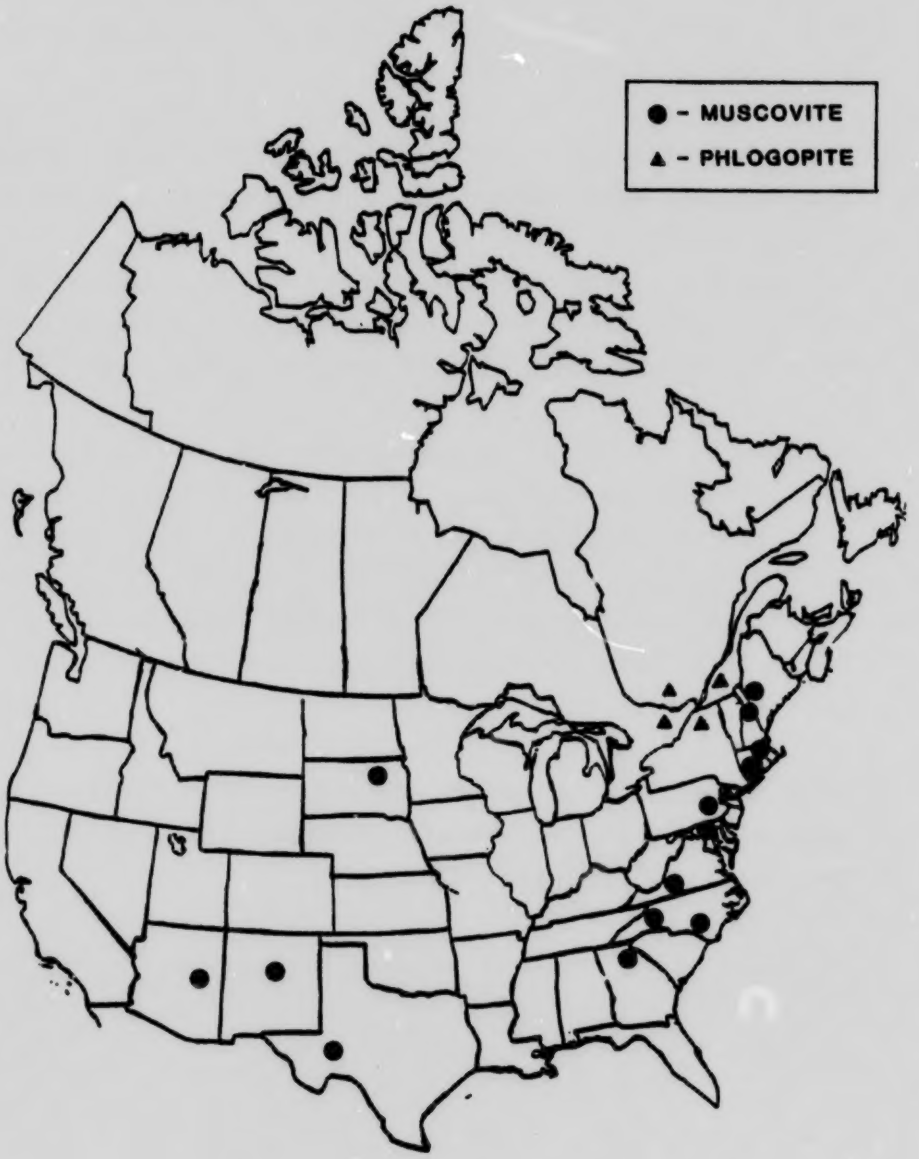
Mica deposits of commercial importance are located in south-central and eastern Ontario and in south-western Quebec.

At present, only one deposit in Quebec is being mined. However, there are other proven mineral deposits of phlogopite mica in Canada for possible future development.[4,5]

Currently, there is one producer of mica in Canada, Marietta Resources International Ltd. Several other companies produce mica infrequently, as a by-product of other mining operations.[5]

Recent production and trade figures are given in Table 2. The location of the major North American deposits are shown in the map on page 6.

Mica refers to a group of silicate minerals with monoclinic crystals which break off easily into thin, tough scales, varying from colorless to black.



MAJOR NORTH AMERICAN MICA DEPOSITS

● - MUSCOVITE
▲ - PHLOGOPITE

TABLE 2 - Canadian Mica Production and Trade

	1978	1979	1980	1981	1982 Preliminary
Production Volume (tonnes)	5,779	11,595	10,369	11,122	10,079
Approx. Value CDN$	700,000	1,700,000	1,900,000	2,400,000	2,200,000
IMPORTS					
Ground (t)	N.A.	N.A.	2,500	3,000	
($)	N.A.	N.A.	680,000	700,035	2,860t
Block, film & sheet (t)	N.A.	N.A.	34	139	842,000$
($)	N.A.	N.A.	83,000	271,000	
Fabricated ($) Total	N.A.	N.A.	2,589,000	2,932,000	2,756,000
United States	N.A.	N.A.	2,338,000	2,598,000	2,230,000
France	N.A.	N.A.	156,000	287,000	420,000
United Kingdom	N.A.	N.A.	42,000	34,000	88,000
Other	N.A.	N.A.	53,000	13,000	28,000
EXPORTS (t)	4,334	8,696	7,777	8,342	7,559

t - tonnes
N.A. - Not Available
Source: Quebec Energy & Resource Department.

Exports of ground mica are distributed as follows:

60% United States
15% South America, Europe, Japan

There are no workable sheet mica deposits available.

The chemical composition of the two major types of mica is given below.[2,4]

TABLE 3 - Chemical Composition of Mica Group

TYPE	COMMON NAME	CHEMICAL FORMULA
Potassium Mica	Muscovite	$H_2KAl_3(SiO_4)_3$
Magnesium Mica	Phlogopite	$H_2KMg_3Al(SiO_4)_3$

Other types of mica are formed by replacing the potassium in muscovite with sodium or lithium. Impurities found in mica form stains which may consist of magnetite or hematite (iron oxide). Iron inclusions decrease the electrical insulating value.[2,4,5]

The major uses of mica are: gypsum board joint-filler cement, reinforcement in thermoplastics; asbestos substitute in cement board and pipe products and brake coatings; as an electrical and heat insulator, for circulations loss control in oil well drilling fluids; lubricant in fire extinguishers, and a reinforcing and stiffening agent in glass and phosphate bonded mica.

The American Society for Testing and Material (ASTM D351) recognizes 12 grades and quality groups of mica which are based on size and visual inspection. The grades range from OOEE to No 6 and the color from V-1 "Clear" to V-12 "Black/Red Stained", depending on color, impurities and physical defects, as indicated in Tables 4 and 5.

In addition to their elasticity, another important property of mica flakes (produced by splitting or grinding) is its "aspect ratio" (AR). This is defined as the average diameter of a flake divided by its thickness. High aspect ratio (HAR) micas have values ranging from 10 to 150. These are valued in plastics and other products where mica is used for reinforcement.

Mica is marketed as cut or uncut block, sheet, splittings and ground. Built-up mica is made by bonding splittings or ground mica with a synthetic resin and compressing at high temperatures to give uniform thickness. Because of the difficulty and cost of handling, natural mica sheet has now become almost obsolete. Built-up mica sheets are easier to handle and are of a uniform quality not found in natural mica. Synthetic micas have also been developed to replace the natural form because of the high purity that can be obtained. It can also provide higher heat resistance than natural mica.[1]

TABLE 4 - ASTM Grade Sizes of Muscovite Uncut Mica Block and Thins (ASTM D351)

ASTM GRADE SIZES	AREA OF MINIMUM RECTANGLE		MINIMUM DIMENSION OF ONE SIDE	
	in^2	equiv., cm^2	in	equiv., mm
00EE Special	100	650	4	100
0EE Special	80	520	4	100
EE Special	60	390	4	100
E Special	48	310	4	100
A-1 Special	36	235	3-1/2	89
No. 1	24	155	3	76
No. 2	15	97	2	51
No. 3	10	65	2	51
No. 4	6	40	1-1/2	38
No. 5	3	20	1	25
No. 5-1/2	2-1/4	15	7/8	22
No. 6	1	6.5	3/4	19

TABLE 5 - Classification of Visual Quality of Block Mica (ASTM D351)

CLASS	NAME
V-1	Clear
V-2	Clear & Slightly Stained
V-3	Fair Stained
V-4	Good Stained
V-5	Stained A Quality
V-5.1	Stained A1 Quality
V-6	Stained B Quality
V-7	Heavy Stained
V-8	Densely Stained
V-9	Black Dotted
V-10	Black Spotted
V-11	Black Stained
V-12	Black/Red Stained

Representative physical properties are shown in Table 6.[4]

TABLE 6 - Comparison Between Muscovite and Phlogopite[4]

CHARACTERISTICS	MUSCOVITE	PHLOGOPITE
Color	Brown, Ruby & Green	Amber to dark Green
Specific Gravity	2.6 to 3.2	2.6 to 3.2
Specific Heat	0.207	0.207
Mohs Hardness	2.8 to 3.2	2.5 to 3.0
Volume Resistivity Ohms/cm^3	$2 \times 10^{13} - 1 \times 10^{17}$	Somewhat less
Modulus of Elasticity (lb/in^2)	approx. 25×10^6	approx. 25×10^6
% Water Constitution	4.5	3.0
Max. Temp. of Use	600°C	1000°C
Flexibility	less	more
Transparency	more	less
Acid Reaction	only hydrofluoric acid	Decomposed by
Dielectric Constant	6.5 to 8.7	5.0 to 6.0
Power Factor (I/Q) for Qualities Classed as Stained or better	0.0001 - 0.0004	0.004 - 0.07

Chemical control is not important, except that in some uses of ground mica, the content of iron oxide present as an impurity must be kept very low. The presence of iron can affect its electrical insulating abilities. Industry prefers that mica be as free from color as possible. Uniformity is also important. A list of other criteria by product type is given in Table 7.

TABLE 7 - Quality Criteria for Some Uses of Mica

PRODUCT TYPE	SIZE/THICKNESS	PURITY	OTHER
Block	0.018cm thick useable area 6.45cm^2	low iron oxide	High dielectric strength, high heat resistance
Splittings	0.003cm thick useable area 4.91cm^2	"	Same
Film	0.003-0.01cm^2 thick	"	From best grades
Dry Ground	Depends on use	"	High electrical chemical and heat resistance, flexibility
e.g.: filler in paints	75 µm	"	High aspect ratio, uniform size fractions
Wet-Ground	45 µm	"	Same as dry-ground
Micronized	38 µm - 15 µm	"	Same as dry-ground

REFERENCES

REFERENCES

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6. Canadian Mining Journal, Annual Mineral Review of 1983, February 1984.

NEPHELINE SYENITE

PROCEDE Plasdex R PROCESS
MONTREAL, QUEBEC

THE NEPHELINE SYENITE INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 3

  2.1 General 2
  2.2 Products Marketed 2

3. PROCESS DESCRIPTION 4 - 22

  3.1 Nepheline Syenite Process Flow 4
  3.2 Ore Crushing and Classification 6
  3.3 Exolon Feed Preparation 9
  3.4 No. 2 Pebble Mill 16
  3.5 No. 3 Pebble Mill 19

4. RESULTS AND DISCUSSION 23 - 48

  4.1 Ore Crushing and Classification 23

    4.11 Electrical Measurements 23
    4.12 Flowrates 25
    4.13 Size Distributions 25
    4.14 Grindability Testing 26
    4.15 Specific Energy Consumption 27

  4.2 Exolon Feed Preparation 29

    4.21 Electrical Measurements 29
    4.22 Flowrates 30
    4.23 Size Distributions 30
    4.24 Specific Energy Consumption 36

TABLE OF CONTENTS
(cont'd)

Page No.

4.3 No. 2 Pebble Mill 37

4.31 Electrical Measurements 37
4.32 Flowrates 38
4.33 Size Distributions 38
4.34 Specific Energy Consumption 39

4.4 No. 3 Pebble Mill 40

4.41 Electrical Measurements 40
4.42 Flowrates 40
4.43 Size Distributions 41
4.44 Specific Energy Consumption 42

4.5 Dust Collection 43

4.51 Electrical Measurements 43
4.52 Specific Energy Consumption 44

4.6 Products Specific Energy Consumption 45

4.61 Glass Products 45
4.62 Ceramic Products 46
4.63 Filler Products 47

5. CONCLUSIONS AND RECOMMENDATIONS 49 - 50

APPENDIX - Industry Review
1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

International Minerals and Chemical Corporation

Plant Location:

Blue Mountain, Ontario

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the nepheline syenite industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

IMC Industry Group (Canada) Ltd., is controlled by International Minerals & Chemical Corporation (Canada) Ltd. (IMC).

2.1 General

IMC operates one of the two Canadian nepheline syenite mills located on Blue Mountain. The mine and plant are about 6.5 km northeast of Nephton, Ontario, at the north-east end of the Blue Mountain Intrusive.

The company began production in 1956 and now employs about 90 people. Its annual production has averaged in recent years around 240,000 tonnes representing about 40% of the North American market. In 1981, the plant was expanded to reach its present capacity of over 300,000 tonnes.

2.2 Products Marketed

The IMC product line is listed in Table 1 with corresponding particle size characteristics and applications.

"A" grade products account for the major fraction of sales with about 65% of the total. The products with the highest fineness command the highest prices. Prices range from just under $20 per short ton for the 30 mesh high fines "B" grade to over $75 for the Apex 700.

TABLE 1 - IMC Product Range

"A" GRADE PRODUCTS (Fe_2O_3 = 0.08%)	PARTICLE SIZE	APPLICATIONS
1. Apex 700	90% minus 10 µm 60% minus 5 µm 40% minus 3 µm	fillers
2. Apex 400	90% minus 20 µm 60% minus 10 µm 38% minus 5 µm	
3. Peak	96% minus 45 µm	ceramics
4. Crest	95% minus 45 µm	
5. C-3	92% minus 45 µm	
6. C-4	88% minus 45 µm	
7. Super 40 "A" Grade	100% minus 425 µm	clear glass manufacture
8. 40 Mesh "A" Grade	97% minus 425 µm	
9. 40 Mesh High Fines "A" Grade	95% minus 425 µm 23% minus 75 µm	
10. 30 Mesh "A" Grade Summit "F"	100% minus 600 µm	
11. 30 Mesh "A" Grade Summit "W"	100% minus 600 µm	
"B" GRADE PRODUCTS ($(Fe_2)_3$ = 0.30%)		
1. Super 40 Mesh "B" Grade	100% minus 425 µm	glass containers
2. 30 Mesh "B" Grade Ridge	99% minus 600 µm	
3. 30 Mesh High Fines "B" Grade	100% minus 600 µm 31% minus 75 µm	
CRUDE		
1. Half Plus	100% Minus 50 mm Plus 25 mm	rockwool

3. PROCESS DESCRIPTION

3.1 Nepheline Syenite Process Flow

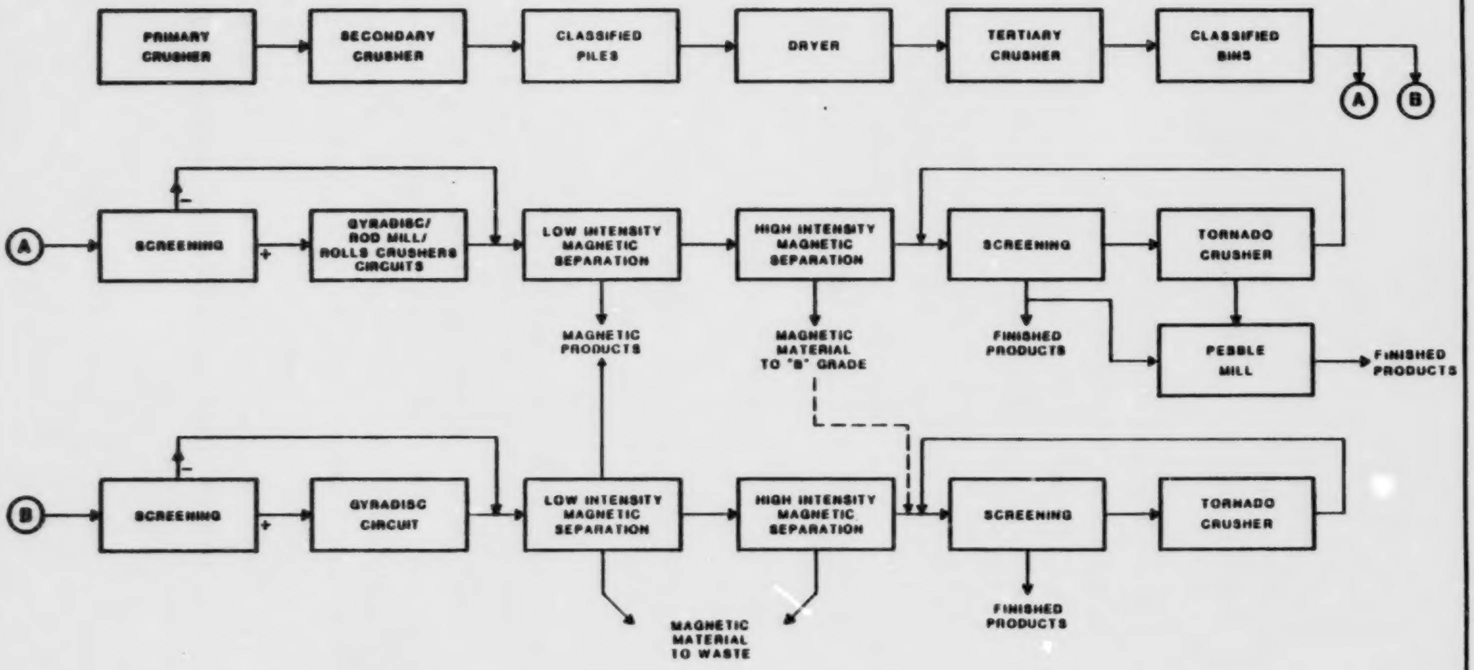
A summarized process flow sheet is presented in Figure I. The process flow sheet can be divided in three major areas:

- Primary ore preparation,
- "A" grade product processing,
- "B" grade product processing.

The first area, primary ore preparation, involves size reduction to minus 19 mm and classification in "A" or "B" grade storage bins. It consists of three crushing stages with a drying operation between the second and third stages. Ore classification is achieved by selective quarrying: prior to blasting, the drill cuttings are analyzed to identify the ore grade on the basis of the iron content. A sample is subjected in the lab to iron removal by means of magnetic separation and graded "A" if it assays less than 0.09% Fe_2O_3; otherwise, it is graded "B". After primary and secondary crushing, the ore is stored in piles according to its grade before going through drying and tertiary crushing. The complete drying of ore is essential before further processing.

The processing for making "A" grade products (second line in the block diagram) consists of screening, crushing, beneficiation by dust wasting and magnetic separation, glass-product screening and milling of the ceramic and filler products. After screening the tertiary crusher product, three different crushing circuits using either rolls crushers, a gyradisc or a rod mill perform a fourth

Figure I - NEPHELINE SYENITE
SUMMARIZED PROCESS FLOW SHEET
IMC - BLUE MOUNTAIN PLANT, ONTARIO


PRIMARY CRUSHER
SECONDARY CRUSHER
CLASSIFIED PILES
DRYER
TERTIARY CRUSHER
CLASSIFIED BINS
A
B
A
SCREENING
−
+
GYRADISC/ ROD MILL/ ROLLS CRUSHERS CIRCUITS
LOW INTENSITY MAGNETIC SEPARATION
HIGH INTENSITY MAGNETIC SEPARATION
SCREENING
TORNADO CRUSHER
MAGNETIC PRODUCTS
MAGNETIC MATERIAL TO "B" GRADE
FINISHED PRODUCTS
PEBBLE MILL
FINISHED PRODUCTS
B
SCREENING
−
+
GYRADISC CIRCUIT
LOW INTENSITY MAGNETIC SEPARATION
HIGH INTENSITY MAGNETIC SEPARATION
SCREENING
TORNADO CRUSHER
MAGNETIC MATERIAL TO WASTE
FINISHED PRODUCTS

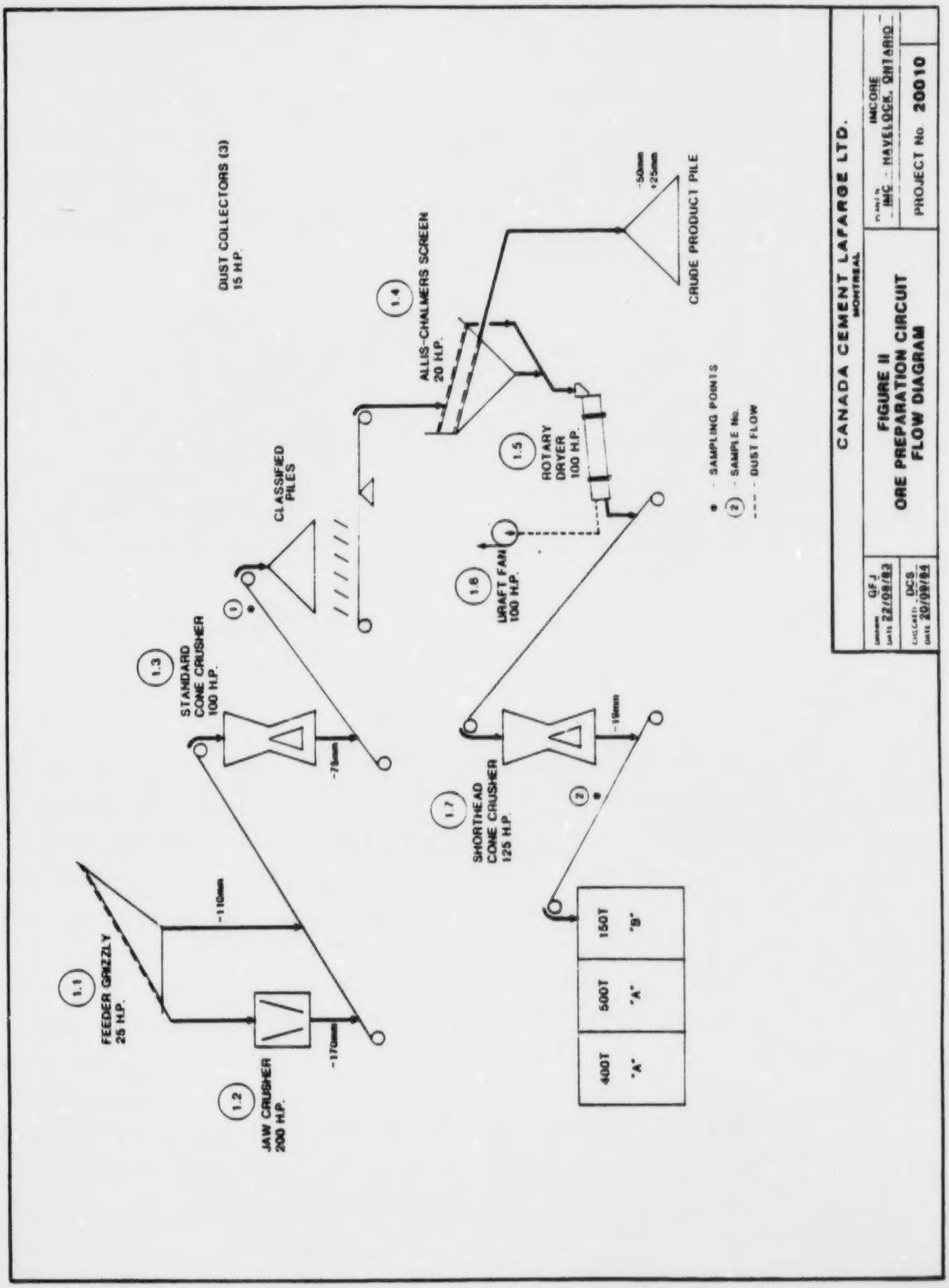
stage of crushing on the oversize. Two different magnetic separators, a low-intensity and a high-intensity type, upgrade the material before the sizing of glass-grade products. Ceramic grades, "Crest" and "Peak", are made in two pebble mill circuits, one of which is also making finer "Apex" filler grades by having a Tornado crusher to reduce coarse particles in the feed to the pebble mill.

"B" grade product processing (third line in the block diagram) resembles that of the "A" grade products. After a preliminary screening, the oversize is crushed in a gyradisc circuit before two steps of magnetic separation. A Tornado crusher reduces further the material to allow the sizing of finer glass-grade products.

3.2 Ore Crushing and Classification

The ore preparation is done in a primary crushing and classification circuit illustrated in Figure II. The equipment monitored during the survey is listed in Table 2.

The graded ore is delivered from the nearby quarry in 40-ton trucks. It is fed into a jaw crusher by a vibrating grizzly feeder that scalps the minus 110 mm fraction. The jaw crusher reduces the rock to approximately minus 170 mm. The primary crusher product joins with the grizzly undersize on a conveyor belt and is fed into a 4-ft standard cone crusher that reduces the rock to minus 75 mm. A radial stacker stockpiles the crushed product outside on piles classified according to the ore grade.


1.1
FEEDER GRIZZLY
25 H.P.
1.2
JAW CRUSHER
200 H.P.
-170mm
-110mm
1.3
STANDARD
CONE CRUSHER
100 H.P.
-75mm
1
CLASSIFIED
PILES
DUST COLLECTORS (3)
15 H.P.
1.4
ALLIS-CHALMERS SCREEN
20 H.P.
-50mm
+25mm
CRUDE PRODUCT PILE
1.5
ROTARY
DRYER
100 H.P.
1.6
DRAFT FAN
100 H.P.
1.7
SHORTHEAD
CONE CRUSHER
125 H.P.
-16mm
2
400T
"A"
500T
"A"
150T
"B"
✱ - SAMPLING POINTS
② - SAMPLE No.
--- - DUST FLOW
DRAWN GFJ
DATE 22/09/83
CHECKED DCS
DATE 20/09/84

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE II
ORE PREPARATION CIRCUIT
FLOW DIAGRAM

PLANT IN IMC - HAVELOCK, ONTARIO
IMCORE

PROJECT No 20010

TABLE 2 - Ore Crushing and Classification - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Feeder Grizzly	25	25
1.2	Jaw Crusher	200	200
1.3	4' Standard Cone Crusher	100	100
1.4	Allis-Chalmers Screen	20	20
1.5	Rotary Dryer	100	100
1.6	Draft Fan	100	100
1.7	4 1/4' Shorthead Cone Crusher	125	125
1.8	Jaw Crusher Dust Collector	15	15
1.9	Cone Crusher Dust Collector	15	15
1.10	A.-C. Screen Dust Collector	15	15

Note: All motors are 550 volts

This part of the primary crushing circuit operates during a single 8-hour shift a day at a rate of about 200 t/h producing 1365 tonnes a day, which is sufficient to supply the milling plant with raw material for a 24-hour period. The daily production is higher when producing the crude product called "Half Plus".

An underground system reclaims the minus 75 mm ore and discharges it on to a double deck screen that separates a mid fraction (-50 mm, +25 mm), which is the crude product called "Half Plus". A weighbelt in the reclaim system regulates the flow of material through the dryer and on to a third stage of crushing at a rate in the range of 80-100 t/h. The ore moisture averages 2-3% and is removed in the drying operation. A 4½-ft shorthead cone crusher reduces the ore to minus 19 mm and the crushed product, now ready for milling, is stored in three milling plant storage silos. Two silos with a combined capacity of 800 tonnes are used for "A" grade ore and the third one with a capacity of 130 tonnes is for "B" grade ore.

This part of the primary circuit operates during two 8-hour shifts per day at an average rate of about 91 t/h.

Figure III gives vertical sections that illustrate the types of cone crushers being used in the primary crushing circuit.

3.3 Exolon* Feed Preparation

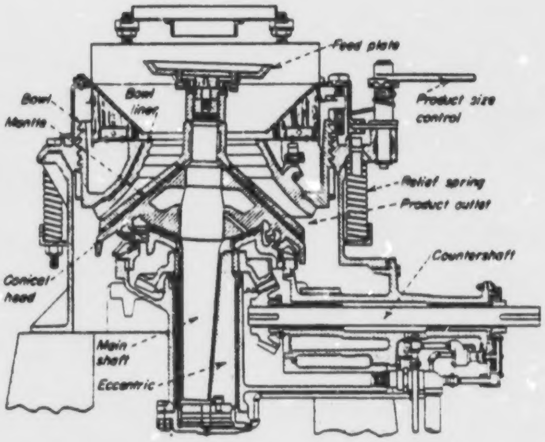
For the remaining process flow, only the "A" grade processing line will be described since the processing of "A" and "B" ores to minus 600 μm is similar.

The "A" grade product processing can be divided in three parts. The first part, identified as the Exolon feed preparation concerns a further ore size reduction through a fourth stage of crushing, in closed circuit with a battery of screens, to produce a minus 600 μm material that is suitable as feed to a first stage of magnetic separation. Five Dings machines (the trade name of a type of low-intensity magnetic drum separator) remove the highly magnetic minerals. The non-magnetic product is stored in the Exolon feed bins, ready for a second stage of magnetic separation.

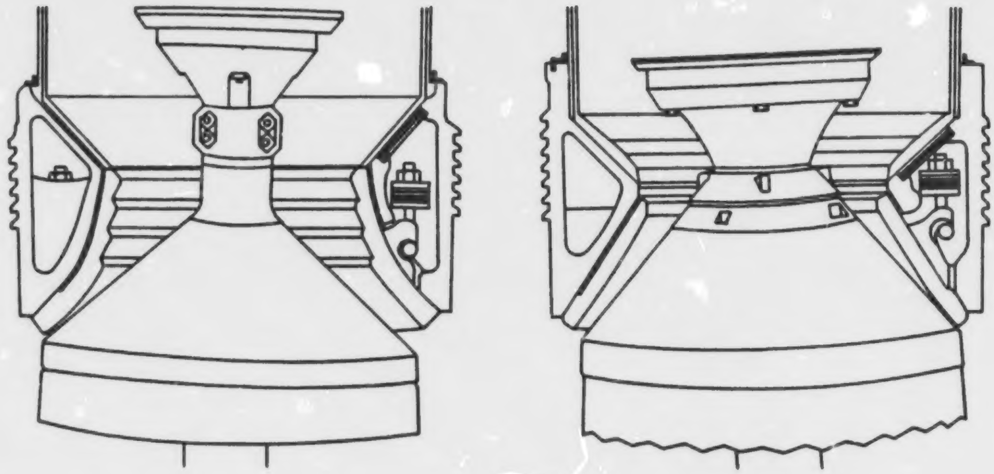
---

* Exolon is the trade name of a type of magnetic separator.

Figure III – PRIMARY CIRCUIT CONE CRUSHERS


Feed plate
Bowl
Bowl liner
Mantle
Product size control
Relief spring
Product outlet
Countershaft
Conical head
Main shaft
Eccentric

Symons Standard Cone Crusher



Standard Crusher

Short Head Crusher

The Exolon feed preparation is illustrated in Figure IV and the equipment list is given in Table 3.

TABLE 3 - Exolon Feed Preparation - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
2.1	4' x 10' Hummer Screens (H1 & H2) (Electrically Vibrated)	-	-
2.2	#1, 2, 3 Rolls Crushers	5 & 15	5 & 15
2.3	#4 Rolls Crusher	5 & 10	5 & 10
2.4	4' x 10' Hummer Screens (H5 & H6)	-	-
2.5	36" Gyradisc Crusher	100	93
2.6	4' x 10' Hummer Screens (H3 & H4)	-	-
2.7	6' x 12' Rod Mill	150	137
2.8	4' x 10' Hummer Screens (H8 & H9) 3' x 10' Derrick Screen (D10)	- 2	- 2

Note: All motors are 550 volts, except Hummer screens which are 230 volts.

The fourth stage of crushing is a complex comminution operation that uses four parallel closed circuits to effect the last size reduction before beneficiation and final glass-grade sizing. Moreover, three different types of crushers are used.

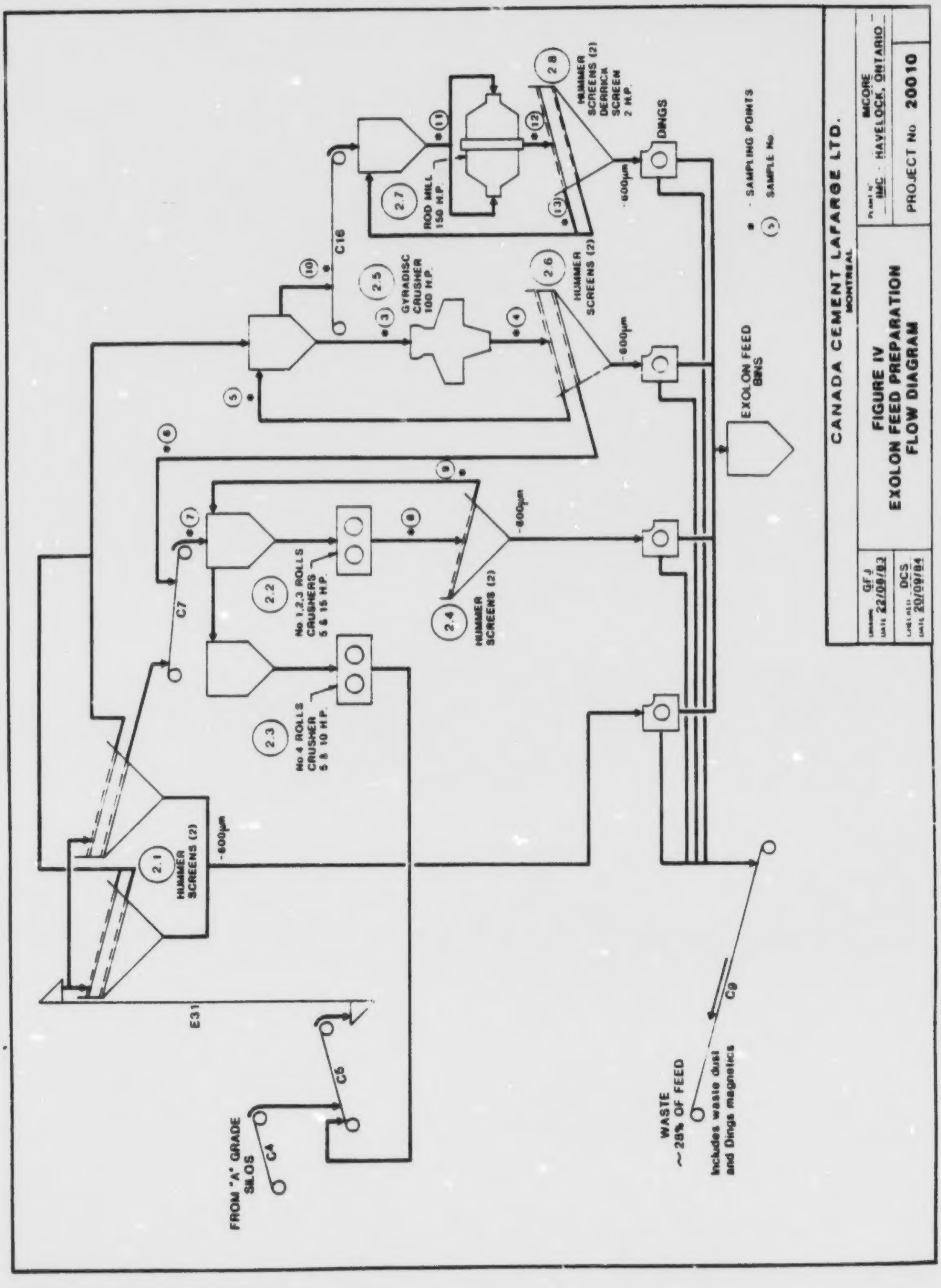

FROM 'A' GRADE SILOS
C4
C5
E31
2.1 HUMMER SCREENS (2)
-600µm
C7
2.2 No 1,2,3 ROLLS CRUSHERS 5 & 15 H.P.
2.3 No 4 ROLLS CRUSHER 5 & 10 H.P.
2.4 HUMMER SCREENS (2)
2.5 GYRADISC CRUSHER 100 H.P.
2.6 HUMMER SCREENS (2)
2.7 ROD MILL 150 H.P.
2.8 HUMMER SCREENS (2) DERRICK SCREEN 2 H.P.
C16
DINGS
EXOLON FEED BINS
WASTE ~28% OF FEED
Includes waste dust and Dings magnetics
C9
3
4
5
6
7
8
9
10
11
12
13
● - SAMPLING POINTS
(5) - SAMPLE No.
CANADA CEMENT LAFARGE LTD.
MONTREAL
PLANT N° IMC - HAVELOCK, ONTARIO
IMCORE
PROJECT No 20010
DRAWN GFJ
DATE 22/08/83
CHECKED DCS
DATE 20/09/84

FIGURE IV
EXOLON FEED PREPARATION
FLOW DIAGRAM

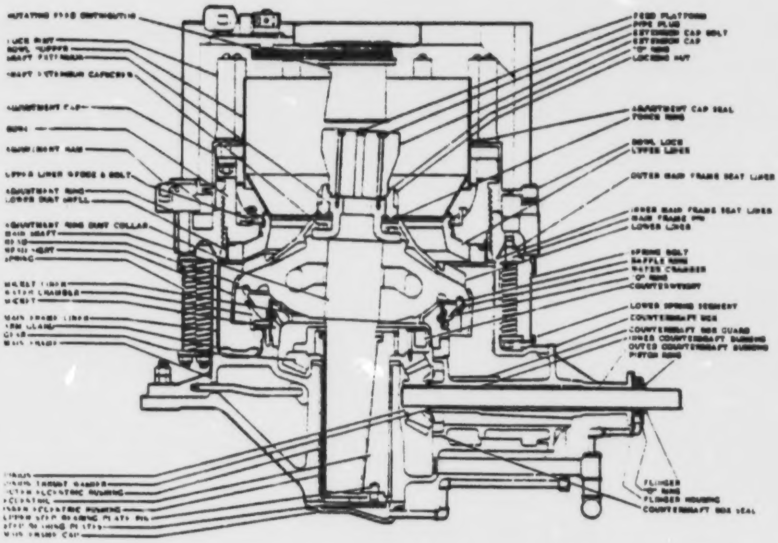
The ore from the "A" grade storage silos is screened on two double-deck Hummer screens (H1 & H2) that scalp the minus 600 µm undersize fraction which can be directly processed by one of the Dings magnetic separators. The oversize of the first deck, a plus 9.5 mm fraction, is conveyed to the gyradisc crusher feed bin; part of the material stored in that bin is then extracted to be stored in the rod mill feed bin. The mid fraction (-9.5 mm, +600 µm) on one of the screens joins the oversize and goes to the gyradisc feed bin; on the other screen, it makes up the fresh feed for the rolls crusher feed bin (#1, #2, #3 rolls crushers).

This group of three rolls crushers (No. 2.2) and the 36" gyradisc crusher (No. 2.5) effect the larger part of the fourth stage of crushing. The latter crusher reduces the coarse material while the former, the fine material. In support to these machines, the #4 rolls crusher (No. 2.3) and the rod mill (No. 2.7) are used as required.

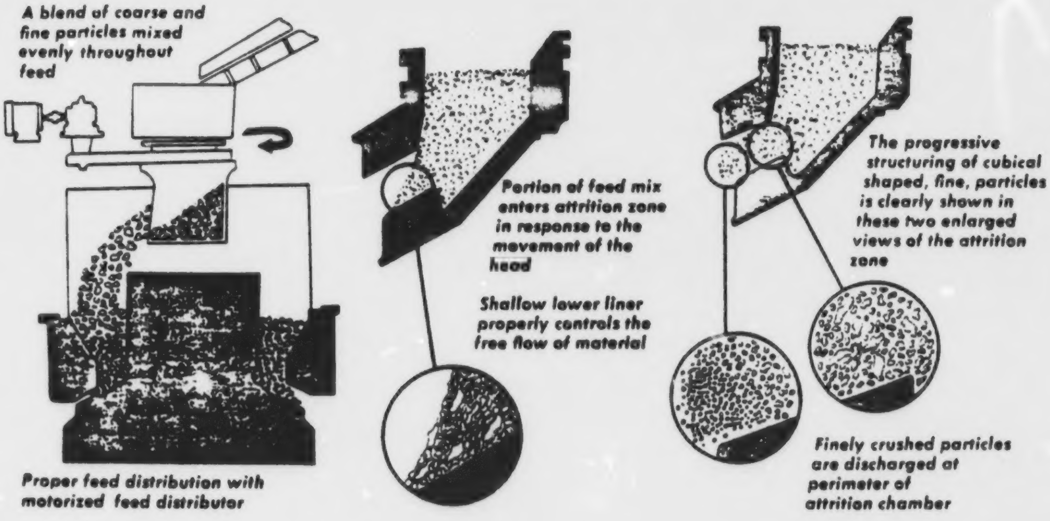
All these crushing circuits but one are closed with a set of two double-deck Hummer screens that recirculate the plus 600 µm and feed the undersize product to one of the four Dings magnetic separators. A special feature of the gyradisc screen is the fact that the intermediate size fraction (-6.3 mm, +600 µm) is diverted to the three rolls crushers circuit giving it additional feed.

Sectional views of the gyradisc crusher and of its operation are given in Figure V while the operation concept of a low-intensity magnetic drum separator is illustrated in Figure VI.

Figure V – GYRADISC CRUSHER


NUTATING FEED DISTRIBUTOR
ADJUSTMENT CAP
BOWL
ADJUSTMENT RING
MAIN SHAFT
SPRING
MAIN FRAME
FEED PLATFORM
PIPE PLUG
EXTENSION CAP BOLT
EXTENSION CAP
"O" RING
LOCKING NUT
ADJUSTMENT CAP SEAL
TORCH RING
BOWL LOCK
UPPER LINER
OUTER MAIN FRAME SEAT LINER
INNER MAIN FRAME SEAT LINER
MAIN FRAME PIN
LOWER LINER
SPRING BOLT
BAFFLE RING
WATER CHAMBER
"O" RING
COUNTERWEIGHT
LOWER SPRING SEGMENT
COUNTERSHAFT BOX
COUNTERSHAFT BOX GUARD
INNER COUNTERSHAFT BUSHING
OUTER COUNTERSHAFT BUSHING
PISTON RING
FLINGER
"O" RING
FLINGER HOUSING
COUNTERSHAFT BOX SEAL

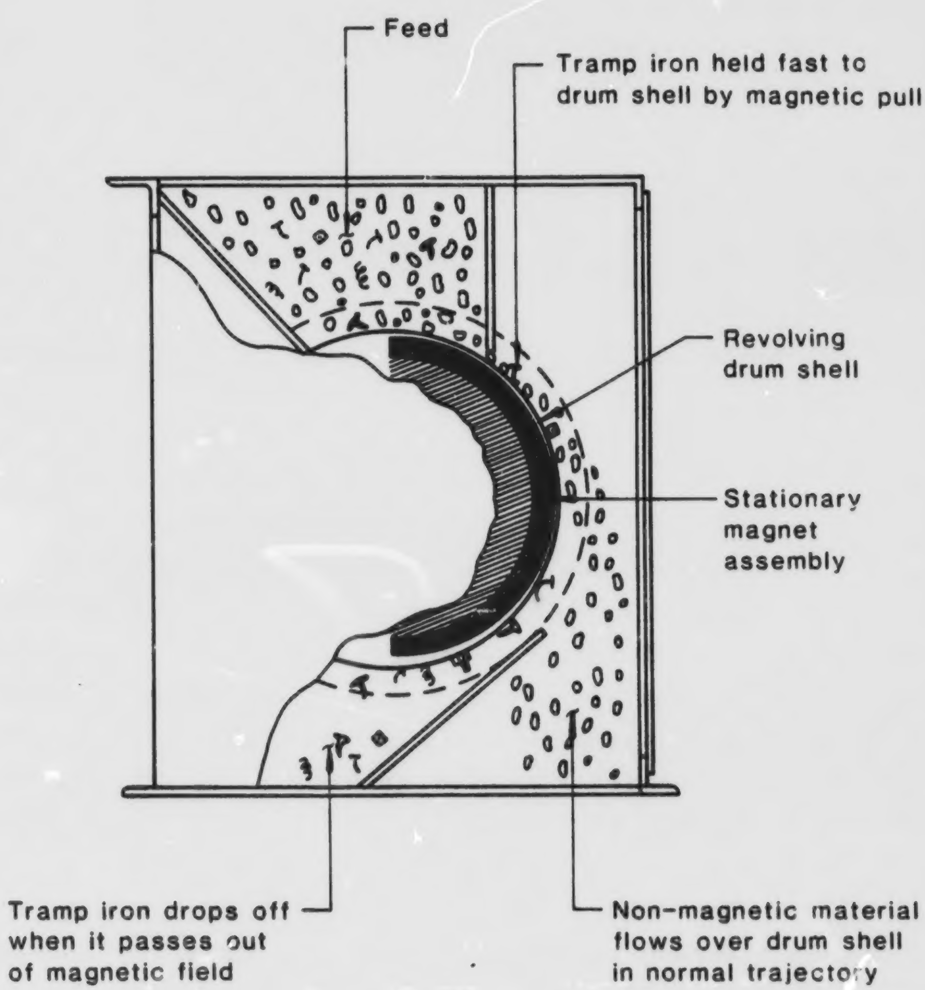
GYRADISC


A blend of coarse and fine particles mixed evenly throughout feed
Proper feed distribution with motorized feed distributor
Portion of feed mix enters attrition zone in response to the movement of the head
Shallow lower liner properly controls the free flow of material
The progressive structuring of cubical shaped, fine, particles is clearly shown in these two enlarged views of the attrition zone
Finely crushed particles are discharged at perimeter of attrition chamber

Operation

SOURCE: REXNORD INC., PROCESS MACHINERY DIVISION

Figure VI - LOW-INTENSITY MAGNETIC DRUM SEPARATOR


Feed
Tramp iron held fast to drum shell by magnetic pull
Revolving drum shell
Stationary magnet assembly
Tramp iron drops off when it passes out of magnetic field
Non-magnetic material flows over drum shell in normal trajectory

3.4 No. 2 Pebble Mill

The second part of the "A" grade product processing, identified as the No. 2 pebble mill circuit, is illustrated in Figure VII. The equipment involved in the survey is listed in Table 4.

TABLE 4 - No. 2 Pebble Mill Circuit - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
3.1	3' x 10' Derrick Screens (D12 & D18)	2	2
3.2	Sweco Screens (2)	3	3
3.3	#2 Pebble Mill	125	120
3.4	#2 Air Separator (Gayco)	25	25

Note: All motors are 550 volts

The non-magnetic product obtained in the first stage of magnetic separation (Dings) is fed to a bank of Exolon high-intensity magnetic separators where more magnetic minerals are removed and rejected to "B" grade product processing. The principle of operation of a high-intensity magnetic separator is illustrated schematically in Figure VIII.

The Exolon separator uses three stages of induced rolls having magnetic fields of increasing intensity, typically from 3000 to 15000 gauss. This type of magnetic separator removes successfully feebly-magnetic minerals such as biotite.

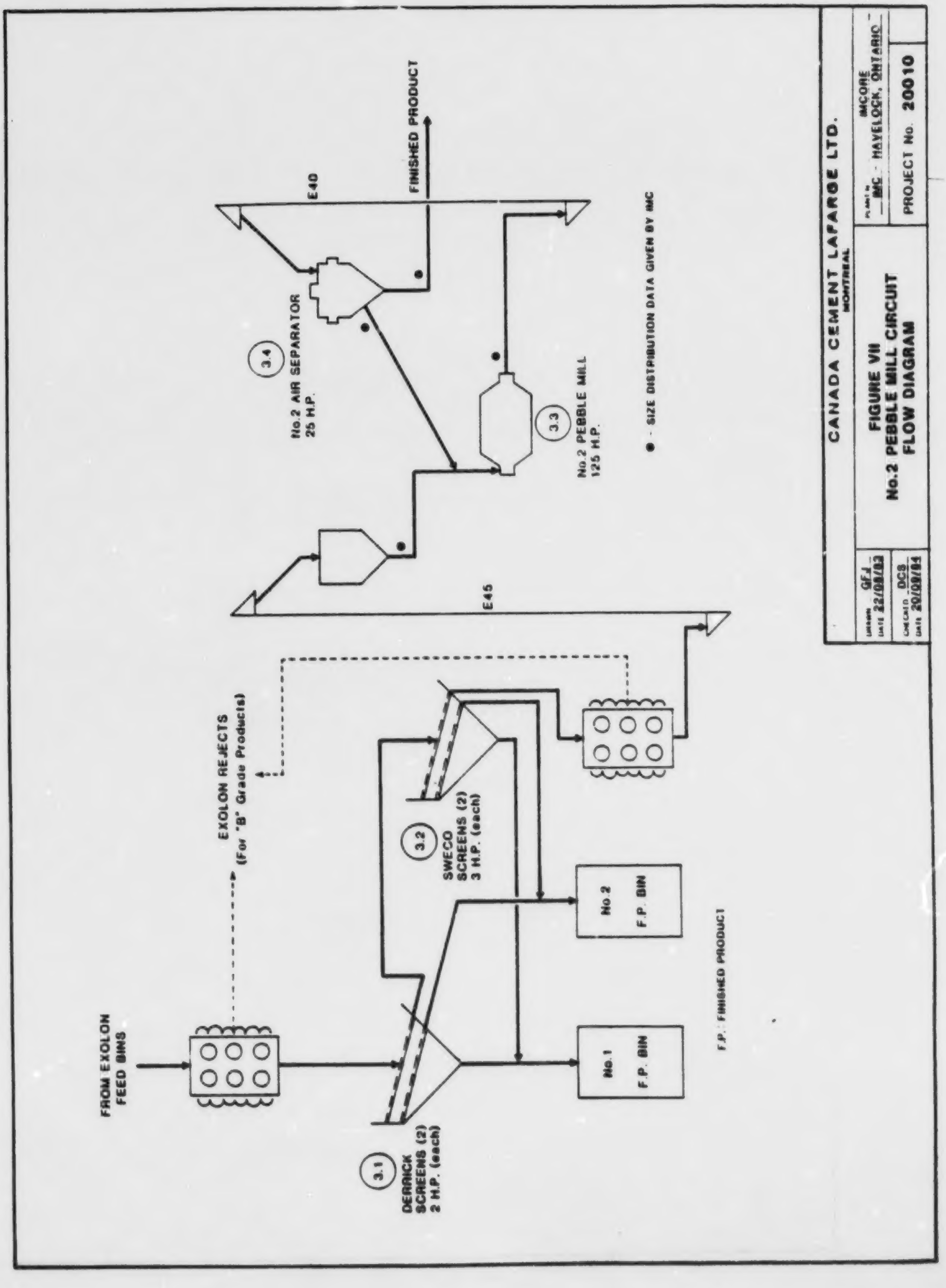
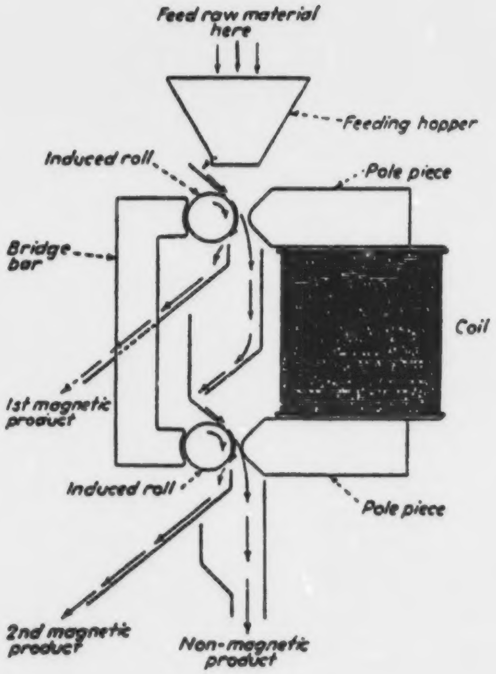


FIGURE VII
No.2 PEBBLE MILL CIRCUIT
FLOW DIAGRAM

FROM EXOLON FEED BINS
3.1
DERRICK SCREENS (2) 2 H.P. (each)
EXOLON REJECTS (For 'B' Grade Products)
3.2
SWECO SCREENS (2) 3 H.P. (each)
No.1 F.P. BIN
No.2 F.P. BIN
F.P.: FINISHED PRODUCT
E45
3.3
No.2 PEBBLE MILL 125 H.P.
3.4
No.2 AIR SEPARATOR 25 H.P.
E40
FINISHED PRODUCT
● - SIZE DISTRIBUTION DATA GIVEN BY IMC
CANADA CEMENT LAFARGE LTD.
MONTREAL
PLANT IMC - IMCORE HAVELOCK, ONTARIO
PROJECT No. 20010
DRAWN GFJ DATE 22/09/83
CHECKED DCS DATE 20/09/84

Figure VIII – HIGH-INTENSITY MAGNETIC SEPARATOR

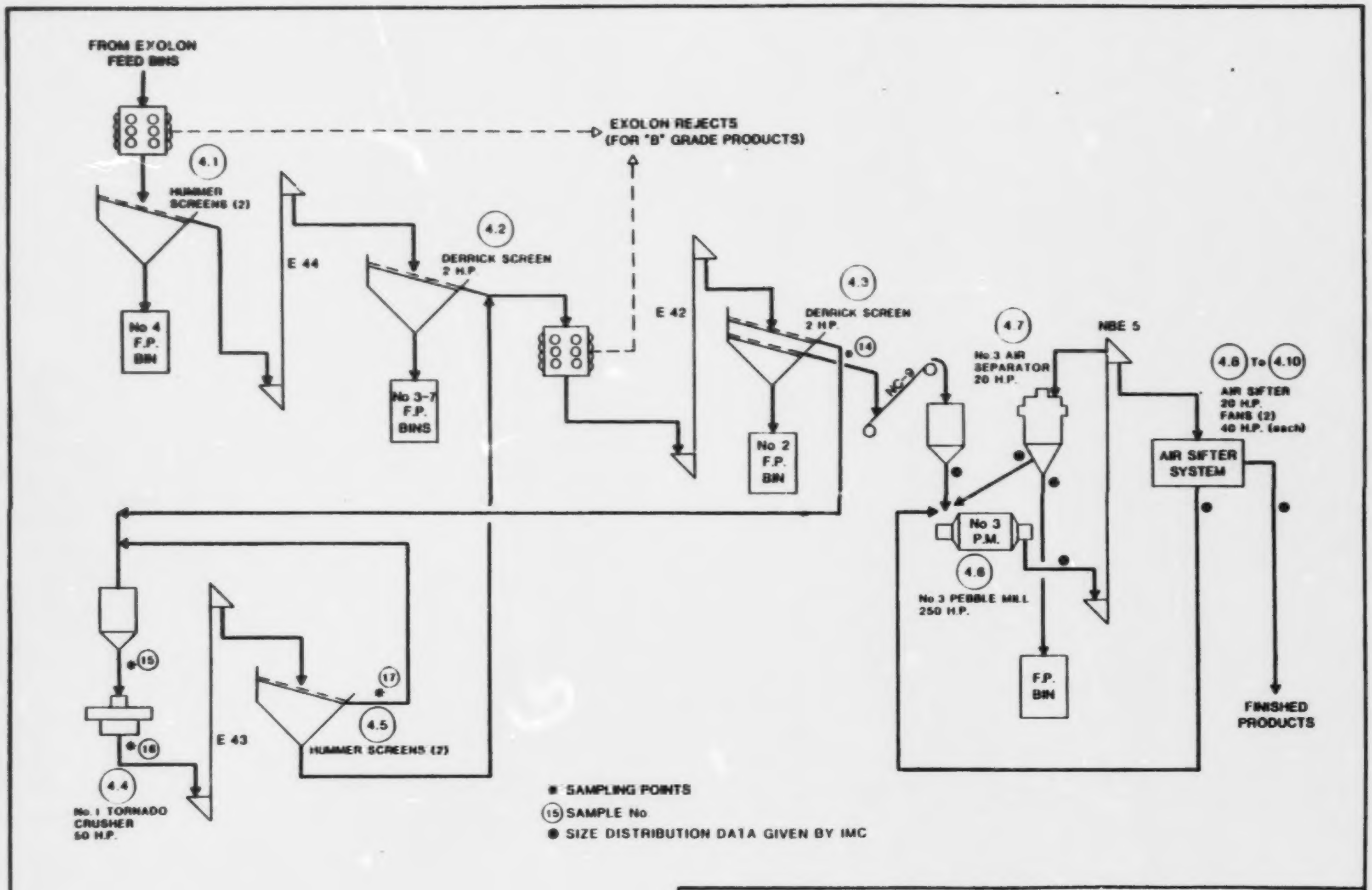

Feed raw material here
Feeding hopper
Induced roll
Pole piece
Bridge bar
Coil
1st magnetic product
Induced roll
Pole piece
2nd magnetic product
Non-magnetic product

After this second stage of magnetic separation, the product is beneficiated to an iron content of 0.08% Fe_2O_3 and is ready for glass-grade product sizing. Two sets of two double-deck vibrating screens are used for that purpose: the first set is a pair of Derrick screens (No. 3.1) with a 355 µm top opening and a 125 µm bottom opening; the second set is a pair of Sweco screens (No. 3.2) with a 600 µm top opening and a 125 µm bottom opening. With this screen arrangement, the fines (-75 µm) are taken out and a super 40 "A" grade product can be obtained with minimal fines content.

The oversize is processed through an Exolon magnetic separator before serving as feed to the No. 2 pebble mill circuit. This circuit, which is closed by a mechanical air separator, produces the "Crest" ceramic grade having a fineness of 95% minus 45 µm.

3.5 No. 3 Pebble Mill

The third part of the "A" grade product processing, identified as the No. 3 pebble mill circuit, is illustrated in Figure IX. The equipment is listed in Table 5.


FROM EXOLON FEED BINS
EXOLON REJECTS (FOR "B" GRADE PRODUCTS)
4.1
HUMMER SCREENS (2)
No 4 F.P. BIN
E 44
4.2
DERRICK SCREEN 2 H.P.
No 3-7 F.P. BINS
E 42
4.3
DERRICK SCREEN 2 H.P.
14
No 2 F.P. BIN
NC-3
4.7
No.3 AIR SEPARATOR 20 H.P.
NBE 5
4.8 To 4.10
AIR SIFTER 20 H.P. FANS (2) 40 H.P. (each)
AIR SIFTER SYSTEM
No 3 P.M.
4.6
No 3 PEBBLE MILL 250 H.P.
F.P. BIN
FINISHED PRODUCTS
15
16
4.4
No. 1 TORNADO CRUSHER 50 H.P.
E 43
17
4.5
HUMMER SCREENS (2)
* SAMPLING POINTS
15 SAMPLE No
● SIZE DISTRIBUTION DATA GIVEN BY IMC

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 23/08/82
CHECKED DCS
DATE 20/09/84

FIGURE IX
No.3 PEBBLE MILL CIRCUIT
FLOW DIAGRAM

PLANT IMCORE DIVISION
IMC - HAVELOCK, ONTARIO

PROJECT No. 20010

TABLE 5 - No. 3 Pebble Mill Circuit - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
4.1	4' x 15' Hummer Screens (H-11 to H-14)	-	-
4.2	4' x 10' Derrick Screen (D17)	2	2
4.3	3' x 10' Derrick Screen (D16)	2	2
4.4	#1 Tornado Crusher	50	48
4.5	4' x 10' Hummer Screens (H15 & H16)	-	-
4.6	#3 Pebble Mill	250	223
4.7	#3 Air Separator (Gayco)	20	21
4.8	Air Sifter	20	-
4.9	Fan #1	40	40
4.10	Fan #2	40	40

Note: All motors are 550 volts, except Hummer screens and air sifter which are 230 volts.

The processing in this pebble mill circuit resembles that of No. 2 pebble mill, except for added features such as an incorporated fine crushing circuit and an air sifter system producing an ultrafine product for filler applications.

As before, the non-magnetic product obtained in the first stage of magnetic separation proceeds to a second stage of magnetic separation. The magnetic rejects go also to "B" grade product processing.

A first screening is done on a series of four single-deck Hummer screens (No. 4.1) with a 500 µm opening. The undersizes make glass-grade products in the 500 µm range. The oversizes are pooled and screened again on a single-deck Derrick screen (No. 4.2) with a 500 µm opening. The undersize makes another glass grade product and the oversize is processed through an Exolon magnetic separator.

The non-magnetic product becomes feed for the No. 3 pebble mill circuit. A double-deck Derrick screen (No. 4.3) with a top opening of 355 µm scalps the feed: the undersize makes a 355 µm glass-grade product and the oversize is directed to the Tornado crusher circuit; only the middle fraction is conveyed to the pebble mill feed bin.

The Tornado crusher (No. 4.4) is part of a closed crushing circuit generating its circulating load with the oversize from a set of two single-deck Hummer screens (No. 4.5) with a 425 µm opening. The undersize product is added back to the feed going through the Exolon magnetic separator mentioned above and, hence, screened again on the double-deck Derrick screen (No. 4.3) preparing feed for the pebble mill. This supplementary crushing and magnetic separation on coarser particles assures the quality and fineness of the No. 3 pebble mill circuit products.

The Tornado crusher operates on a centrifugal principle reducing material by impact only. It is equipped with a high-speed rotating table using blades to project particles against the wall of the cylindrical housing.

The No. 3 pebble mill is a circuit closed by a mechanical air separator that produces the "Peak" ceramic grade having a fineness of up to 98% minus 45 µm.

The No. 3 pebble mill can also deliver a feed that serves to produce the sub-sieve filler grade products, Apex 400 and Apex 700. The mill discharge, which is stored in the separator feed bin, can be partly diverted to the air sifter system (No. 4.8 to 4.10) to produce on a part-time basis these products while the "Peak" production out of the air separator is maintained.

4. RESULTS AND DISCUSSION

The results of the data collection campaign are grouped under six headings:

- Ore crushing and classification
- Exolon feed preparation
- No. 2 pebble mill
- No. 3 pebble mill
- Dust collection
- Specific energy consumption by product

4.1 Ore Crushing and Classification

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the ore crushing and classification circuit is presented in Table 6.

TABLE 6 - Ore Crushing and Classification

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
1.1	FEEDER GRIZZLY	25	-	-	-
1.2	JAW CRUSHER	200	78	28	56
1.3	4' STANDARD CONE CRUSHER	100	45	11	28
1.4	ALLIS-CHALMERS SCREEN	20	-	-	-
1.5	ROTARY DRYER	100	54	54	54
1.6	DRAFT FAN	100	75	75	75
1.7	4½' SHORTHEAD CONE CRUSHER	125	25	20	24
1.8	JAW CRUSHER DUST COLLECTOR	15	10	10	10
1.9	CONE CRUSHERS DUST COLLECTOR	15	10	10	10
1.10	A.-C. SCREEN DUST COLLECTOR	15	9	9	9

The power level observations for the three crushers of the circuit were obtained by recording each motor power demand. For other equipment having stable electric loads, the Amprobe meter or an ammeter was used. The Allis-Chalmers screen was not operational and the feeder was not monitored (the latter is usually a small electric load).

From the examination of these measurements the following comments can be made:

- The loading of the crushers is low: compared to installed power of 317 kW (425 HP), the average power demand totals only 108 kW, or 34%; Table 7 presents the electric loading of the crusher motors.

TABLE 7 - Crusher Motor Load

CRUSHER	% NOMINAL POWER
Primary	38
Secondary	38
Tertiary	26
Average	34

- The power demand of the auxiliary equipment, particularly the dryer and its draft fan, is high at 158 kW and represents about one and a half times that of the comminution equipment.

4.12 Flowrates

The crushing circuit being made up of two parts, two flowrates must be considered to determine the average hourly production rate needed for specific power consumption calculations.

The average flowrate through the first part of the circuit consisting of the primary and secondary crushers is estimated in the following manner. In an 8-hour shift, only 7 hours are considered operational, giving a daily production of 1360 tonnes, an average of 194 t/h and a utilization factor of about 90%. This part of the circuit operates intermittently due to the random arrival rate of trucks feeding the primary crusher; this causes time when crushers run idle.

The second part of the circuit, comprising the dryer and tertiary crusher, operates continuously during two 8-hour shifts of which 15 hours are considered operational. Thus, the average production rate is 91 t/h.

4.13 Size Distributions

The primary crusher feed size distribution was minus 900 mm, plus 50 mm and mainly minus 450 mm, plus 150 mm.

The primary product size distribution was estimated to be minus 175 mm with the bulk in the 50 mm x 100 mm range.

The distributions for the secondary and tertiary crushers products are given in Table 8.

TABLE 8 - Ore Crushing Size Distributions

SAMPLE # mm	#1 SECONDARY CRUSHER PRODUCT (% Passing)	#2 TERTIARY CRUSHER PRODUCT (% Passing)
100	100	
75	95.7	
50	87.5	
38.1	73.0	
31.5	-	100
25.0	56.8	98.7
19.0	48.6	94.2
12.5	38.0	81.3
9.5	32.7	68.3
4.75	24.5	50.6
2.36	20.8	42.0
1.18	16.6	33.5
0.600	11.1	21.1
0.300	7.1	20.9
0.150	4.2	4.3

The secondary crusher product distribution was adjusted to account for a bias caused by the small sample size (24 kg) (see working papers).

At the time of sampling, the Allis-Chalmers screen was not in operation to remove the minus 50 mm, plus 25 mm fraction ("Half Plus" crude product), which means the secondary crusher product distribution is also the tertiary crusher feed distribution.

4.14 Grindability Testing

The grindability testing by both the Hardgrove and Bond test procedures was performed on the secondary crusher product.

The Hardgrove Index (HGI) found on this nepheline syenite ore is 41. The Bond Index was found to be 13.85 kWh/tonne, which is similar to the Bond Index calculated from the Hardgrove Index (14.82 kWh/ton).

These results suggest that this ore is difficult to grind and equivalent to very hard cement clinkers and average quartz. It also implies that this mineral is hard and probably abrasive, but not necessarily that it is difficult to crush.

4.15 Specific Energy Consumption

The procedure used to calculate the specific consumption consists simply in adding up the average power demand of each motor and dividing this total power demand by the average production rate. As the ore crushing circuit is made up of two parts, each with a particular production rate, the specific consumption for the circuit is obtained by adding the specific consumptions calculated for each of the two parts.

For the primary and secondary crushers, the total power demand amounts to 104 kW, including the dust collectors (Equipment No.1.8 and 1.9). Dividing by 194 t/h a specific consumption of 0.535 kWh/t is found. By taking only the crushers' motors power demand (84 kW), a specific consumption of 0.432 kWh/t is determined for comminution alone.

The same calculations are made for the second part comprising the dryer and tertiary crusher. Total power demand amounts to 162 kW, the average production rate is 91 t/h and a specific consumption of 1.79 kWh/t is found. The consumption for comminution alone represents only 0.265 kWh/t.

The following table gives a summary of these results.

TABLE 9 - Ore Crushing and Classification Detailed Specific Power Consumption

		kWh/tonne	%
Primary and Secondary Crushers	Crushing	0.43	81
	Auxiliaries	0.10	19
	Total	0.53	100
Dryer and Tertiary Crusher	Crushing	0.26	15
	Auxiliaries	1.53	85
	Total	1.79	100

Table 10 gives the results for the complete circuit.

TABLE 10 - Ore Crushing and Classification Specific Power Consumption

	kWh/tonne	%
Crushing	0.70	30
Auxiliaries	1.62	70
Total	2.32	100

The results demonstrate two facts already mentioned in 4.11:

- The low consumption for comminution alone shown by the low value of specific consumption for crushing.

- The high total consumption caused by the dryer and, particularly, the draft fan whose power demand

(75 kW) appears to be disproportionate to the moisture content of the rock (2-3% H_2O). This situation is highlighted in Table 9 by the low percentage of comminution consumption for the second part of the crushing circuit.

4.2 Exolon Feed Preparation

4.21 Electrical Measurements

The electrical measurements obtained in the Exolon feed preparation circuit are presented in Table 11.

TABLE 11 - Exolon Feed Preparation

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
2.1	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.2	#1, 2, 3 ROLLS CRUSHERS	3 x 5	8.3	8.3	8.3
		3 x 15	29	29	29
2.3	#4 ROLLS CRUSHER	5	1.7	1.7	1.7
		10	5.0	5.0	5.0
2.4	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.5	36" GYRADISC CRUSHER	100	44	44	44
2.6	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.7	6' x 12' ROD MILL	150	74	74	74
2.8	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
	3' x 10' DERRICK SCREEN	2	0.8	0.8	0.8

The Hummer screens are electrically-vibrated and operated on 230 volt power supply; their power demand has been calculated on the basis of 4 amps and a 0.85 power factor giving 0.8 kW on each screen. The rolls crushers power demand (No. 2.2) is expressed as a combined demand for one motor type. The power consumption of the Dings magnetic separators was not monitored but is considered to be low.

These measurements indicate that the comminution equipment, with a power demand of 162 kW, takes 96% of the total demand. The rod mill comes out clearly as the largest consumer. The total of all rolls crushers at 44 kW equals the gyradisc demand.

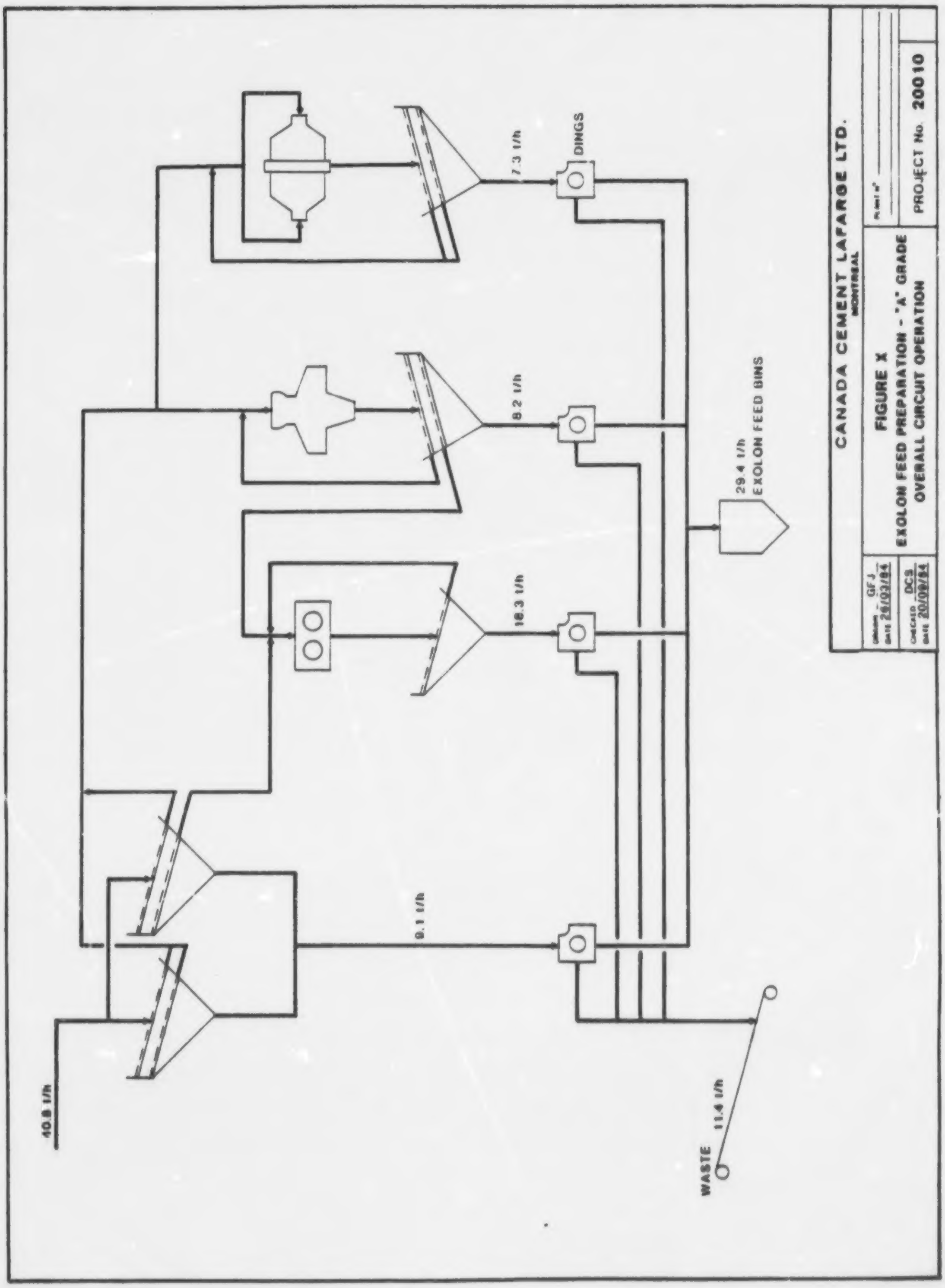
4.22 Flowrates

No flowrate measurements were made during the field work period. The flowrates needed for computing specific energy consumptions are based on plant records and operating experience.

The circuit processes 980 tonnes per day of crushed ore extracted from the "A" grade storage silos. This is equivalent to 40.8 t/h. A typical circuit operation is illustrated in the flow diagram in Figure X. Production rates are given for each stream of minus 600 µm material feeding the Dings separators. On this flow diagram, the #4 rolls crusher is neglected (its production is rated at 3.6 t/h) as it produces a circulating load which is mixed back into the incoming feed to the circuit. The recovery of non-magnetic material after the Dings separators is assumed to be 72%, which translates into a production rate of 29.4 t/h of Exolon feed.

4.23 Size Distributions

The size distributions obtained from the screen analysis of the 11 samples taken in the circuit are presented in Tables 12-14.


40.8 t/h
9.1 t/h
18.3 t/h
8.2 t/h
7.3 t/h
DINGS
29.4 t/h
EXOLON FEED BINS
WASTE
11.4 t/h
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE X
EXOLON FEED PREPARATION - "A" GRADE
OVERALL CIRCUIT OPERATION
DRAWN GFJ
DATE 26/03/84
CHECKED DCS
DATE 20/09/84
PROJECT No. 20010

The feed extracted from the "A" grade silos is screened to scalp off the minus 600 µm fraction which is directly processed by a Dings separator. The tertiary crusher product distribution (Table 8) confirms the flowrate for this stream (9.1 t/h).

Secondly, the size distributions for the flows around the gyradisc crusher are given in Table 12.

TABLE 12 - Gyradisc Crusher Size Distributions

(% Passing)

SAMPLE # mm	#3 GYRADISC FEED BIN DISCHARGE	#4 GYRADISC PRODUCT	#5 RECIRCULATION TO GYRADISC FEED BIN	#6 GYRADISC PRODUCT TO ROLLS FEED SUPPLY
25.0	100	100	100	
19.0	97.2	98.9	99.2	
12.5	90.1	90.6	89.4	
9.5	84.1	77.9	67.4	100
4.75	74.1	54.6	16.3	99.4
2.36	64.7	41.7	3.1	87.8
1.18	45.2	31.9	1.2	71.4
0.600	12.3	17.5	0.6	39.8
0.300	2.5	7.8	0.3	19.0
0.150	0.5	1.6	0.2	8.2

An examination of the data brings out an anomaly: the gyradisc product (#4) appears to be coarser than the feed bin discharge (#3), specifically in the 1.18 to 12.5 mm range. This situation can only be due to a non-representative sample. The high fineness of the gyradisc feed is noteworthy and adds to the preceding remark: for instance, the minus 600 µm in the product should be more than double the one in the feed, according to information from the manufacturer, i.e., in the order of 30-35% instead of the 17.5% reported.

The two other distributions (#5 and #6) give an indication of the screening performance and the amount of recirculation and feed supplied to the rolls feed bin. By observing the separation size and comparing with previous distributions (#2 and #3), the flow through the gyradisc is estimated at about 29 t/h, the recirculating flow (oversize) at 10 t/h and the supply flow to rolls (midsize) at 10.9 t/h.

The size distributions concerning the roll crushers are given in Table 13. The rolls product distribution (#8) exhibits the same phenomenon as in the case of the gyradisc: it also appears to be coarser than the rolls feed supply (#7), especially in the range of minus 1.18 mm and less. This fact could be due again to a non-representative sample collected from the top of the screen deck; the minus 600 µm in the product should be in the range of 40-60% from a material balance viewpoint, if the production rate (16.3 t/h) and screening capacity (32-36 t/h) are considered. In fact, examination of the recirculation distribution seems to indicate a flow through the rolls crushers of about 30 t/h with a recirculation of 13.6 t/h representing 45% of the crushers flow. The difference (55%) would be represented by the production flowrate (16.3 t/h). This hypothesis would confirm a 60% minus 600 µm in the rolls product distribution.

TABLE 13 - Roll Crushers Size Distributions

(% Passing)

SAMPLE # mm	#7 ROLLS FEED SUPPLY	#8 ROLLS PRODUCT	#9 RECIRCULATION TO ROLLS FEED BIN
12.5	100		
9.5	99.5	100	100
4.75	97.0	99.4	99.3
2.36	85.2	87.2	83.0
1.18	65.4	62.3	52.3
0.600	30.9	25.9	11.4
0.300	13.7	10.1	1.7
0.150	5.8	4.2	0.3

The rolls feed supply distribution (#7) is a composite of a part of the mid-size from the scalping screens (see Figure IV) and of the mid-size screened from the gyradisc product (distribution #6).

The size distributions relating to the rod mill are given in Table 14.

TABLE 14 - Rod Mill Size Distributions

(% Passing)

SAMPLE # mm	#10 GYRADISC FEED BIN SUPPLY TO ROD MILL FEED BIN	#11 ROD MILL FEED BIN DISCHARGE	#12 ROD MILL PRODUCT	#13 RECIRCULATION TO ROD MILL FEED BIN
25.0	100			
19.0	95.8			
12.5	80.3	100		
9.5	58.4	99.0	100	100
4.75	28.1	94.7	99.9	98.9
2.36	15.5	89.8	99.3	96.9
1.18	6.9	77.9	91.4	85.1
0.600	1.5	23.4	38.0	14.3
0.300	0.5	7.4	19.1	1.4
0.150	0.2	2.1	10.4	0.4

The distribution (#10) of the supply to rod mill from the gyradisc feed bin appears surprisingly coarse when compared to both feed bin discharge and recirculation distributions (#11 and #13). It can probably be explained by bin segregation whereby larger particles may lie preferentially at the bin periphery (pile effect) while the finer material stays in the center. Distribution #10, from a sample taken on the belt conveyor reclaiming material from the side of the gyradisc feed bin, would illustrate the occurrence of this phenomenon from time to time. Furthermore, the segregation phenomenon is also present in the rod mill feed bin as demonstrated by comparison of both feed bin discharge and recirculation distributions (#11 and #13) with that of feed supply (#10). The coarser size of the latter is not represented in the distribution of the feed bin discharge (mill feed), indicating probably that, at the time of sampling, larger particles were falling to the bin periphery instead of being funnelled into the discharge.

Comparison of the recirculation distribution (#13) with that of feed bin discharge (#11), although the latter may be highly affected by segregation, points to a high circulating load, in the order of two to three times the production rate. A similar comparison between recirculation (#13) and rod mill product (#12) leads to the same observation for the rod mill. Flow would be in the order of 27 t/h with about 70% represented by recirculation (20 t/h).

4.24 Specific Energy Consumption

The three comminution machines are compared to show their relative impact on power consumption. The circuit specific energy consumption is established on the basis of beneficiated ore (Exolon feed). The data does not include the consumption of Dings magnetic separators.

Table 15 gives the power consumption data for each of the three crushing circuits by using average power observations and production rates. The data indicates the large differences in specific consumption that exists between these crushing circuits, particularly in the case of the rod mill. No comment can be made in regard to specific consumption as a function of product quality, which could be defined as maximum production having minimum amount of minus 150 µm particles (high-quality glass grade), because the crusher product size distributions have been found inaccurate.

TABLE 15 - Fourth Stage Crushing
Specific Power Consumption

		kWh/tonne	%
Rolls Crushers (#1, 2, 3)	Crushing Auxiliaries	2.28 0.10	96 4
	Total	2.38	100
Gyradisc Crusher	Crushing Auxiliaries	5.39 0.20	96 4
	Total	5.59	100
Rod Mill	Crushing Auxiliaries	10.2 0.3	97 3
	Total	10.5	100

The average specific power consumption for the fourth stage of crushing is given in Table 16.

TABLE 16 - Exolon Feed Preparation
Specific Power Consumption

	kWh/tonne	%
Crushing	5.51	96
Auxiliaries	0.25	4
Total	5.76	100

4.3 No. 2 Pebble Mill

4.31 Electrical Measurements

The electrical measurements obtained in the No. 2 pebble mill circuit are presented in Table 17.

TABLE 17 - No. 2 Pebble Mill

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
3.1	3' x 10' DERRICK SCREENS (2)	2	1.6	1.6	1.6
3.2	SWECO SCREENS (2)	2 x 3	-	-	-
3.3	#2 PEBBLE MILL	125	75	75	75
3.4	#2 SEPARATOR	25	8	8	8

The No. 2 pebble mill drive is only loaded at 80% of nominal power. No measurement was taken on the Sweco screens. The power demand for the Exolon magnetic separator was not monitored but is considered to be low (estimated power demand would be 0.6 kW per unit).

4.32 Flowrates

The production rate established for Exolon feed preparation is assumed to be divided among the Exolon units in a proportion that directs close to one third of the flow rate to the No. 2 pebble mill circuit and two thirds to the No. 3 pebble mill circuit. The split is thus 9.3 t/h and 20.1 t/h, respectively.

The recovery of beneficiated material from the Exolon separators is estimated to be 90% and, as the rejects are not lost but downgraded to "B" products, this factor does not reduce the production rate in regard to glass-grade products.

Production rate data used to compute specific power consumptions was supplied by IMC.

4.33 Size Distributions

The size distributions around the No. 2 pebble mill, which were supplied by plant staff, are shown in Table 18. Few comments need to be made, except to note that the finished product has a 95% passing 45 µm, which is the Crest grade specification. Other ceramic grades, namely C-3 and C-4, have a lower 45 µm specification, 92% and 88% passing, respectively.

TABLE 18 - No. 2 Pebble Mill Circuit Size Distributions (% Passing)

µm	Fresh Feed	Mill Discharge	Separator Rejects	Finished Product
850	100	-	-	-
600	96.4	-	-	-
500	66.1	-	-	-
425	35.8	-	-	-
300	3.8	-	-	-
250	1.5	-	-	-
106	-	100	100	-
75	-	98.0	97.0	100
45	-	80.8	58.9	99.7
30	-	55.2	19.5	88.6
20	-	36.3	6.0	66.8
10	-	20.5	4.0	38.0
6	-	14.7	3.7	25.0
2	-	9.8	3.5	11.8

4.34 Specific Energy Consumption

The specific energy consumption is computed on the basis of the power demand of both pebble mill and air separator (Equipment Nos. 3.3 & 3.4). The resulting specific consumption is given in Table 19.

TABLE 19 - No. 2 Pebble Mill Specific Power Consumption

	kWh/tonne	%
Grinding	35.9	90
Auxiliaries	3.9	10
Total	39.8	100

This performance can be compared to the reference reported in Taggart's Handbook of Mineral Dressing for a conical mill (8' x 48") grinding a nepheline syenite product to

95% minus 45 µm at 1 t/h using 85 HP (separator included): the specific consumption amounted in that case to 63.3 kWh/tonne, which is considerably more than what is reported in the above table.

4.4 No. 3 Pebble Mill

4.41 Electrical Measurements

The electrical measurements obtained in the No. 3 pebble mill circuit are presented in Table 20.

The No. 3 pebble mill is run fully loaded at 98% of nominal power. The circuit includes a closed-circuit crusher, the Tornado crusher, well loaded at 75% of nominal power and an air sifter system, lightly loaded at 43% of nominal power.

TABLE 20 - No. 3 Pebble Mill

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
4.1	4' x 15' Hummer Screens (4)	-	3.2	3.2	3.2
4.2	4' x 10' Derrick Screen	2	0.8	0.8	0.8
4.3	3' x 10' Derrick Screen	2	0.8	0.8	0.8
4.4	#1 Tornado Crusher	50	28	28	28
4.5	4' x 10' Hummer Screens (2)	-	1.6	1.6	1.6
4.6	#3 Pebble Mill	250	183	183	183
4.7	#3 Air Separator	20	7	7	7
4.8	Air Sifter	20	6	6	6
4.9	Fan #1	40	12	12	12
4.10	Fan #2	40	15	15	15

4.42 Flowrates

Production rate data was supplied by IMC.

4.43 Size Distributions

The size distributions concerning the Tornado crusher operation are given in Table 21.

TABLE 21 - Tornado Crusher Size Distributions

(% Passing)

SAMPLE # mm	#14 TORNADO MILL FEED SUPPLY	#15 TORNADO MILL FEED BIN DISCHARGE	#16 TORNADO MILL PRODUCT	#17 RECIRCULATION TO TORNADO FEED BIN
4.75	100			
2.36	99.9		100	100
1.18	99.4	100	99.9	99.9
0.600	70.9	84.5	92.9	82.2
0.300	8.7	10.0	33.1	8.2
0.150	1.5	1.4	14.2	1.6

Both feed supply and recirculation distributions (#14 and #17) appear to be clearly the result of screening with the same screen aperture (425 μm), somewhat above the 300 μm reported in the screen analysis. The comparison of these with the feed bin discharge distribution (#15) points to a greater resemblance with the recirculation distribution, indicating probably a high circulating load. The Tornado mill product distribution (#16), when compared to feed bin discharge, reveals a good amount of comminution work being performed.

The size distributions of the pebble mill system are shown in Table 22. The finished product (Peak) from the air separator has better than the specified 96% minus 45 μm.

TABLE 22 - No. 3 Pebble Mill Circuit
Size Distributions (% Passing)

µm	Fresh Feed	Mill Discharge	Separator Rejects	Finished Product
850	100	-	-	-
600	96.5	-	-	-
500	72.6	-	-	-
425	47.1	-	-	-
300	14.4	-	-	-
250	8.9	-	-	-
106	-	100	100	-
75	-	98.0	97.0	100
45	-	91.5	84.0	98.0
30	-	73.2	62.2	93.1
20	-	50.4	41.3	81.3
10	-	28.3	22.8	55.0
6	-	20.0	16.7	39.3
2	-	12.0	11.0	19.2

4.44 Specific Energy Consumption

Separate specific consumptions are computed for the Tornado crusher, the pebble mill and the air sifter system on the basis of average power observations (Table 20) and average production rates. The power consumption of screens (No. 4.1, 4.2 and 4.3) ahead of pebble mill feed bin is not included in these results. The air sifter system power demand is assumed to remain constant whatever product is made. Table 23 presents these various results.

TABLE 23 - No. 3 Pebble Mill Circuit
Specific Power Consumption

SYSTEM	kWh/tonne			% TOTAL COMMINUTION
	GRINDING	AUXIL.	TOTAL	
Tornado Crusher	5.14	.30	5.44	95
Pebble Mill	43.9	1.6	45.5	96
Air Sifter (Apex 400)	-	26.0	26.0	-
Air Sifter (Apex 700)	-	36.4	36.4	-

The No. 3 pebble mill power consumption is somewhat higher than that of No. 2 pebble mill as it could be expected for a finer product. The consumption for the sifters is shown in auxiliaries and represents for the Apex products an addition to the energy already expended in the pebble mill.

The range of specific consumptions found for both pebble mills presents a close resemblance with that of clinker grinding, in the cement industry, for a similar size range. It shows that nepheline syenite is a hard mineral to grind and the grindability indices reported in Section 4.14 are appropriate.

4.5 Dust Collection

4.51 Electrical Measurements

Throughout the milling plant, dust control is effected by a bank of thirteen dust collectors that are distributed along the entire process flowline without being attached to specific crushing or grinding circuits. Amperage measurements were made on the fan motors of these various units. Using the nominal power rating and a power factor estimate, power demand estimates have been calculated for each of these motors. The data is presented in Table 24.

TABLE 24 - Milling Plant Dust Collectors

UNIT NO.	MOTOR HP	AMPS	POWER FACTOR	kW
1	40	31	0.70	21
2	45	24	0.60	14
3	30	29	0.75	21
4 (north)	30	18	0.64	11
(south)	25	20	0.71	14
5	40	33	0.72	23
6	15	13	0.73	9
7	25	14	0.62	8
8	50	40	0.71	27
9	50	35	0.68	23
10	40	31	0.70	21
11	15	12	0.71	8
12	40	30	0.69	20
13	40	31	0.70	21
Total	485	-	-	241

The summation makes a sizeable total power demand that must be taken into account to calculate specific power consumptions for various products. The total power demand represents a 67% loading of total installed power.

4.52 Specific Energy Consumption

Because it was not possible to assign individual dust collector units to specific circuits, the power consumption for dust collection is allocated to products on the basis of total plant production rate. The plant daily production is estimated at 980 tonnes, making an average production rate of 40.8 t/h.

By dividing the total power demand of 241 kW by the average production rate, a specific power consumption of 5.90 kWh/tonne is obtained for dust collection. This value will be used for calculating specific consumption by product.

4.6 Products Specific Energy Consumption

4.61 Glass Products

An average specific energy consumption for glass products is established on a cumulative basis including ore crushing, Exolon feed preparation, final sizing and dust collection. The summation of these various specific consumptions is presented in Table 25 as well as their distribution.

The ore crushing specific consumption is adjusted to take into account tailings lost as wasted dust and Dings rejects (overall recovery factor of 72%). The final sizing consumption includes 25% of the Tornado circuit power demand, this being the fraction allocated to glass products.

TABLE 25 - Glass Products Power Consumption
Average Specific Consumption

	kWh/tonne	%
Ore Crushing	3.22	21
Exolon Feed Preparation	5.76	37
Final Sizing	0.60	4
Dust Collection	5.90	38
Total Consumption	15.5	100

The main comments are as follows:

- The Exolon feed preparation accounts for a large fraction of total consumption [illegible] the comminution consumption due to the fourth stage of crushing explains 96% of this item.

- The total comminution consumption is only 44%. This is due mainly to dust collection, which accounts for 38%, and ore drying.

4.62 Ceramic Products

The specific energy consumption for ceramic products is established on a cumulative basis including ore crushing, Exolon feed preparation, pebble milling and dust collection. The summation of these various items is presented in Table 26 for the respective pebble mill circuits.

The ore crushing consumption is adjusted according to the process recovery factor (72%). A proportion of 75% of the Tornado crusher power demand is allocated to No. 3 pebble mill.

TABLE 26 - Ceramic Products Power Consumption
Average Specific Consumption

	CREST		PEAK	
	No. 2 Pebble Mill		No. 3 Pebble Mill	
	kWh/tonne	%	kWh/tonne	%
Ore Crushing	3.22	6	3.22	5
Exolon Feed Preparation	5.76	10	5.76	9
Tornado Crusher	-	-	5.32	8
Pebble Milling	39.8	73	45.5	69
Dust Collection	5.90	11	5.90	9
Total Consumption	54.7	100	65.7	100

As expected, milling power consumption is the main item accounting for about 70% of total consumption for both ceramic products. As a consequence, the total comminution consumption, which is about 80%, is also high and even more so, in the case of No. 3 pebble mill, on account of the Tornado crusher consumption. Admittedly, the latter item depends on the arbitrary power demand (75%) allocated to No. 3 pebble mill production. But, on milling alone, No. 3 pebble mill consumption is 14.4% higher than that of No. 2 pebble mill, which is understandable, considering the difference in product fineness. Including the Tornado consumption, it becomes 27.8% higher than for No. 2 pebble mill product: this is felt to be too large a difference between the two milling circuits despite the difference in product fineness.

4.63 Filler Products

The specific energy consumption for Apex 400 and Apex 700 products is presented in Table 27 by simply adding the specific air sifter consumption to the already established No. 3 pebble mill consumption.

TABLE 27 - Filler Products Power Consumption

	APEX 400		APEX 700	
	kWh/tonne	%	kWh/tonne	%
No. 3 Pebble Mill	65.7	72	65.7	64
Air Sifter System	26.0	28	36.4	36
Total Consumption	91.7	100	102.1	100

The data show the importance taken by the air sifter in power consumption, accounting for about one third of the total. Because this consumption is solely for classification, the total for comminution decreases proportionally. But the large consumption impact of the air sifter system may not be fully significant in view of its low electric loading (see 4.41): it may be oversized for the feed rate it is operated at, meaning that a higher feed rate generating a higher production rate would probably improve the specific consumption determined in this survey. It must be added that little information was available because the air sifter system is considered proprietary to IMC.

In nepheline syenite processing, the power consumption can vary from 15 kWh/tonne for glass grade products, to about 60 kWh/tonne for ceramic grade products and over 90 kWh/tonne for filler grade products. Product sizes range from minus 600 µm for glass grade products, to 90-98% minus 45 µm for ceramic grade products and 90% minus 20 µm or 10 µm for filler grade products.

Comminution is not a major factor in the manufacturing cost, particularly in the case of glass products, where it accounts for about 2-3%. For ceramic and filler products, it is more important, ranging from 5 to 10% of manufacturing cost.

The potential for savings concerning comminution proper appears to be small. Primary and secondary crushing entails a power consumption quite typical for these comminution steps. The same applies for tertiary crushing but, at that stage, the drying operation increases the overall specific consumption for crushed and classified ore. In fact, the dryer drive and draft fan combined consumption represents more than 60% of total ore crushing power consumption. This consumption (1.42 kWh/tonne) appears high and may be the result of an oversizing of the rotary dryer system. Also, it is noted that the draft fan runs at maximum power, which raises the question of a possible excess in drying gases. If it is so, thermal energy is wasted. The drying operation warrants further study and may show a potential for both thermal and electric energy savings.

In the area of Exolon feed preparation, the same comment of minimal savings applies, except to note that the rod mill system is the largest consumer among fourth-stage crushers. This system may present some quality advantage that was not made known during the field work; the imperfect sampling of crusher products could not give any clue in this regard. Therefore, if no quality advantage is obtained from it, the rod mill should be used the least.

The pebble mills performance seems to be good and in line with what should be expected. The use of the Tornado circuit adds significantly to the specific consumption of products made in the No. 3 pebble mill circuit. It would obviously be advantageous to minimize its use.

Because the processing of nepheline syenite is a long sequence of repeated crushing, screening and magnetic separation, dust collection requirements are large and necessitate the use of numerous units with a total installed power of 485 HP (milling plant only). Power demand for dust collection has been estimated at 241 kW and thus represents a major factor in overall power consumption, particularly in the case of glass products. A thorough study would be needed to uncover any potential for savings in that area.

On a product basis, it is seen, for glass products, that power consumption for auxiliaries is larger than for comminution itself (56% versus 44%). The total consumption is typical for the products. The power consumption for ceramic products is also believed to be typical of fine materials. Any savings potential lies in the rod mill and Tornado crusher circuits. As for filler products, the consumption increase caused by the finer classification effected in the air sifter is high and accounts for one third of the product total consumption.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing[1,2]

Nepheline syenite is a quartz free feldspathic igneous rock consisting of nepheline, potash and soda feldspar, and accessory mafic minerals such as biotite, hornblende and magnetite. It is characterized by high alumina and alkali content and relatively low silica. Nepheline syenite resembles granite in texture and hardness, but is white in colour and relatively common. There are known occurrences in Russia, Scandinavia, India, Canada, United States and other parts of the world.

Although nepheline syenite is a rock type present in many parts of Canada, its industrial application is limited to those deposits from which iron-bearing accessory minerals can readily be removed. Its major uses are in the glass and ceramic industries.

The use of nepheline syenite as a raw material for glass, ceramic and the filler industries was first developed in Canada, the world's sole producer for many years. Canada's only competitor in the field, Norway, began nepheline syenite mining and milling in 1961. Other countries, the USSR and the United States, mine the mineral for other uses, specifically as a source of aluminum in the USSR and for railway ballast and roofing granules in the USA.

Over the years, nepheline syenite has become preferred to feldspar as a source of essential alumina and alkalis for glass manufacture. Its use results in more rapid melting of the bath at lower temperatures than with feldspar, thus reducing fuel consumption, lengthening the life of furnace refractories and improving the yield and quality of glass. Other industrial uses include ceramic glazes, enamels, and fillers in paints, papers, plastics and foam rubber.

The glass industry accounts for about 70% of nepheline syenite consumption. Use of finely ground material in the ceramics industry and as a filler has grown more rapidly in recent years than consumption for glassmaking. Today, Canada remains the world's foremost producer of nepheline syenite as an industrial raw material with a total capacity amounting to over 800,000 tonnes per year compared to Norway's 225,000 tonnes a year. Typically, Canada exports up to 75% of its production with about 85% of exports going to the United States.

Nepheline syenite ore is mined by the open pit method in Canada while underground mining is used in Norway. The iron content in the Canadian ore body is distributed quite uniformly, but selective quarrying, blending of quarry material, and careful pit development are necessary to ensure a mill product capable of meeting consumer specifications.

Processing of nepheline syenite starts with the diamond drill core evaluations. Analyses of the drill cuttings are made prior to blasting large blocks of material. Ore is graded accordingly.

In the milling plant, the blended ore is reduced in jaw and cone crushers before being dried. The dried ore is further reduced in a tertiary crushing circuit using impact or cone crushers. The crushed ore is then screened to remove the minus 600 µm material and the oversize is further reduced to minus 600 µm using various crushers such as rolls, gyradisc or rod mill.

Magnetite and iron-bearing minerals are then removed using first, low intensity magnetic separators and secondly, high intensity magnetic separators. Two product grades are thus obtained depending on the ore selected in the quarry, one with a Fe_2O_3 content of less than 0.08% and the other with a Fe_2O_3 content of less than 0.[illegible]%. These two product grades are sized by series of vibrating screens to produce minus 600, 425 and 300 µm products for the glass industry.

Fine products of the highest grade used in the ceramic, paint and plastics industries are ground in pebble mills operating in closed circuit with air classifiers. The air-classified products range from minus 75 µm to minus 10 µm.

Canadian Industry

Initial interest in the commercial possibilities of the mineral began in 1912 when various deposits were sampled and examined by a company interested in a process for extracting alumina from silicate minerals.[3]

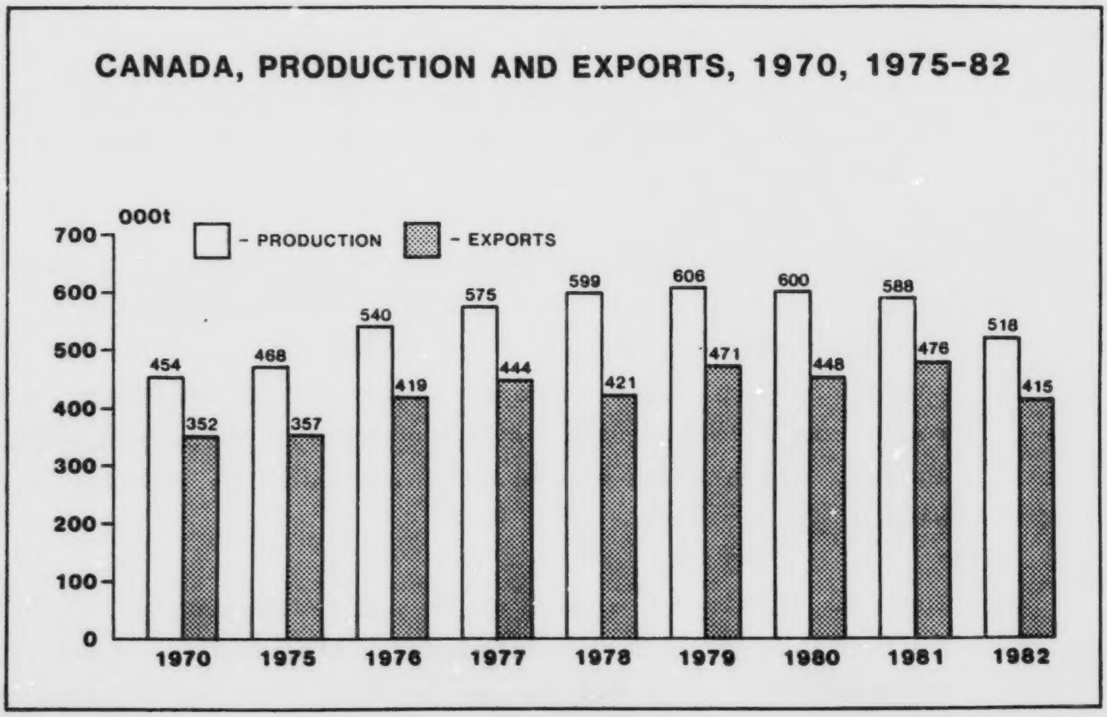
But Canada's nepheline syenite industry really began in 1932 with the staking of fine claims on Blue Mountain in Methuen Township, 40 km northeast of Peterborough, Ontario. Today, there are two mills in operation on Blue Mountain processing rock from several quarries. The deposit is pearshaped, approximately 8 kilometres long, and between 1.6 and 2.5 kilometres wide.[1]

Indusmin Limited, a subsidiary of Falconbridge Nickel Mines Limited, is the larger producer, its annual capacity having been raised to 420,000 tonnes in 1979. It has a large range of products based on combinations of different particle sizes and iron content. The operation is located at Nephton, Ontario, and exploits the southwest end of the deposit.

IMC Industry Group (Canada) Limited, a wholly owned subsidiary of International Minerals & Chemicals Corporation (IMC) works the northeast end of the deposit. IMC completed an expansion in 1981 that increased capacity by 25% to well over 300,000 tonnes annually. The range of products was also enlarged and some higher value grades are now available.

The production volumes, expressed as producers' shipments, and exports during recent years are shown in the diagram below.

FIGURE 1 - Canada, Production and Exports, 1970, 1975-82[4]
(in thousand tonnes)



Source: Canadian Minerals Yearbook 1982, EMR Canada.

From 1977 through 1981, shipments of Canadian nepheline syenite have been stable at about 600,000 tonnes per year. But, starting in 1981, the industry has been affected by the recession; a 15% fall in shipments occurred in 1982.

Table 1 gives production, exports and domestic consumption breakdowns for 1981 and 1982.

TABLE 1 - Canada, Nepheline Syenite Production, Exports, and Consumption, 1981 and 1982[4]

	1981		1982	
	tonnes	$000	tonnes	$000
Production (shipments)	588 000	16,700,000	518 000	17,338,000
Exports				
United States	399 071	13,423,000	373 930	13,557,000
Italy	12 203	435,000	6 834	495,000
Australia	11 295	408,000	1 537	121,000
Netherlands	8 654	358,000	24 490	1,014,000
United Kingdom	3 740	175,000	4 751	256,000
France	1 149	121,000	821	93,000
Taiwan	311	72,000	526	193,000
Other countries	39 858	266,000	1 896	193,000
Total	476 281	15,258,000	414 785	15,765,000
Consumption[1]				
Glass and Glass Fibre	66 591			
Ceramic Products	16 217			
Insulation	11 368			
Paints	2 039			
Rubber Products	689			
Others[2]	830			
Total	97 734	..	..	..

Sources: Statistics Canada; Energy, Mines and Resources, Canada

[1] Available data, as reported by consumers.

[2] Includes frits and enamel, foundry, plastics, electrical apparatus and other minor uses.

P Preliminary: .. Not available.

Market Outlook

The rapid growth of nepheline syenite consumption in the 60's and early 70's was largely due to the recognition by glassmakers of its superior qualities in terms of chemical consistency, supply reliability and low cost compared to its chief competitor, feldspar. In recent years, competition for Canadian nepheline syenite has continued to come from feldspar and aplite produced in the United States. The substitutability of these inputs for glass and ceramics and the high cost of transport relative to unit value have created stable market areas. The borders of these markets are as much dependent on freight rates as on prices.[4]

The outlook for nepheline syenite continues to be good, although the 1982 recession in the world economy interrupted growth. It is expected that the glass and ceramic industries will continue to be the principal users of nepheline syenite. The wide range of products, now offered by both IMC and Indusmin, and the established high quality of products should allow an increase of sales in the medium term. However, any large scale increase in shipments will depend on the performance of the glass and ceramics industry, which in turn is dependent on the North American economy in general.[4]

Exports offshore should continue to grow with expansion of European markets, since the only western European nepheline syenite producer, Norsk Nefelin, division of Elkem A/S, is already operating at capacity.

PRODUCT CHARACTERISTICS[5]

Industrially, there are no standard specifications for nepheline syenite. However, nepheline syenite used for glass-making is typically a product with a size distribution between 600 and 75 µm, an alumina content in excess of 23%, an alkali content in excess of 14% and an iron oxide content of less than 0.08%.

For the ceramic industry, a fineness of less than 75 µm is required as well as its qualities of high fluxing and low level of iron and other impurities.

In the extender pigment and filler industries, the important qualities are the following: high dry brightness, chemical uniformity and inertness, high bulking value and high specific index of refraction.

In general, market requirements vary and, for instance, North American markets require 0.08% Fe_2O_3 or less while European markets accept 0.1% Fe_2O_3 content. Norwegian nepheline syenite products are higher in alumina and alkalis than Canadian ones. Other contaminating metallic ions must be at acceptably low levels and refractory minerals must be absent.

Typical chemical and physical characteristics are presented in the following tables.

TABLE 2 - Chemical Analysis of a Nepheline Syenite Product[6]

Component	%
SiO_2	60.1
Al_2O_3	23.3
Fe_2O_3	0.07
CaO	0.7
MgO	0.1
Na_2O	10.1
K_2O	4.9
LOI	0.65

TABLE 3 - Properties of Nepheline Syenite[6]

Specific Gravity	2.61
Hardness (Mohs scale)	5 - 6
Refractive Index	1.53
pH	9.6
Pyrometric Cone	6 - 7

QUALITY CRITERIA[5,6]

Although, taken as a whole, the deposits are remarkably uniform in chemical and mineralogical comsumption, it has been found that in certain areas, the rock is less amenable to treatment. Consequently, control of the chemical composition of the final product must and does commence before actual mining operations begin. In the laboratory, core samples from the undeveloped quarry zones are subjected to a treatment duplicating, on a small scale, the actual mill flow sheet and complete chemical analyses are made of each product. This method ensures uniform chemical composition of future production.

During quarry exploitation, chip samples are taken and analyzed for chemical uniformity and iron content. Any irregularities require blending of rock from several faces.

Quality control in the mill is concerned primarily with particle size distribution. Regular checks are made of the screen products. Sieve analysis and sub-sieve analysis are carried out for both the glass grade and ceramic grade products. It has been established that, where mill conditions are constant, there is a correlation between sieve and sub-sieve analyses.

Iron assays are made on mill samples to provide a measure of performance of the magnetic separation stage in the mill.

Each shipment made is drawn from the storage bins in an established pattern to guard against variation due to segregation. Also, complete sieve and iron content analyses of representative samples are reported and maintained for each shipment. Complete chemical analysis and checks for fired colour, fusibility and biotite specking are made monthly.

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REFERENCES

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POTASH

PHOCIDE Planolex JR PROCESS
MONTREAL, QUEBEC

THE POTASH INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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TABLE OF CONTENTS

		Page No.
1.	INTRODUCTION	1
2.	PROCESS DESCRIPTION	2 - 9
2.1	Potash Process Flow	2
2.2	Ore Processing	4
2.3	Product Screening and Compaction	6
3.	RESULTS AND DISCUSSION	10 - 20
3.1	Ore Processing	10
3.11	Electrical Measurements	10
3.12	Flowrates	11
3.13	Size Distribution	12
3.14	Grindability	14
3.15	Energy Consumption	15
3.2	Product Screening and Compaction	16
3.21	Electrical Measurements	16
3.22	Flowrates	17
3.23	Size Distribution	18
3.24	Energy Consumption	19
4.	CONCLUSION AND RECOMMENDATIONS	21 - 22

APPENDIX - Industry Review
- 1. General Information
- 2. Product Characteristics

REFERENCES

1. INTRODUCTION

Cooperating Company:

P.C.S. Mining Ltd.
Cory Division

Plant Location:

Saskatoon, Saskatchewan

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the potash industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. PROCESS DESCRIPTION

2.1 Potash Process Flow

The flowline at the PCS Cory Division mill involves a range of process principles (Fig. I). The processes include impact crushing and screening, desliming, flotation, centrifuging and product crystallization. It is a wet process from the secondary screening stage to flotation and crystallization. Product screening and handling follow the drying operations.

The Cory process is arranged into four major steps:

- ore processing and flotation feed preparation,
- flotation with tails and slimes handling,
- two crystallization circuits for manufacture of white products,
- pink product screening and compaction.

The last step includes final drying and screening for both the soluble and refined white products.

Due to the seasonal nature of the market, the Cory plant requires extensive product handling and storage facilities so that product stocks can be built up to meet the requirements of peak demand.

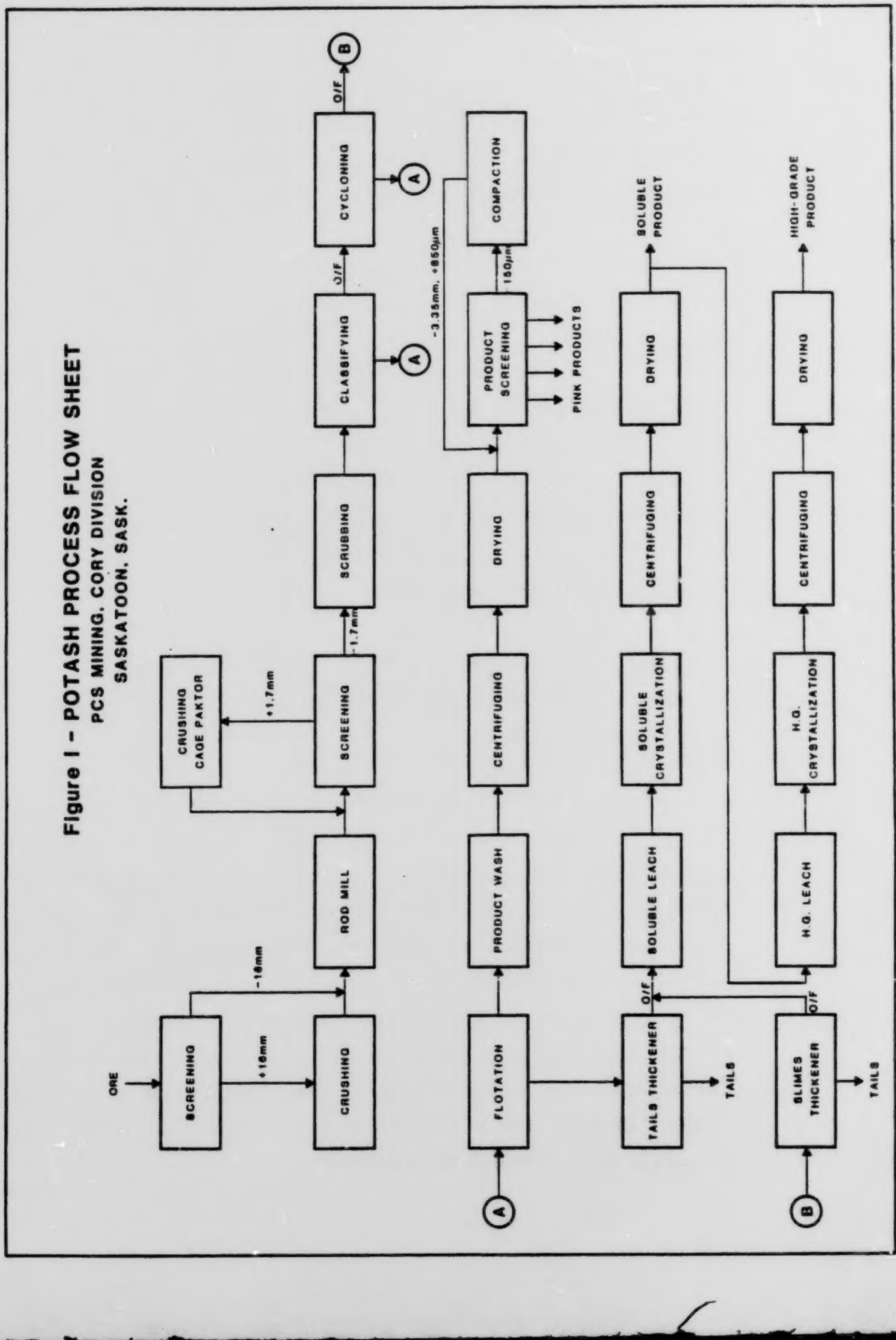


Figure I - POTASH PROCESS FLOW SHEET
PCS MINING, CORY DIVISION
SASKATOON, SASK.

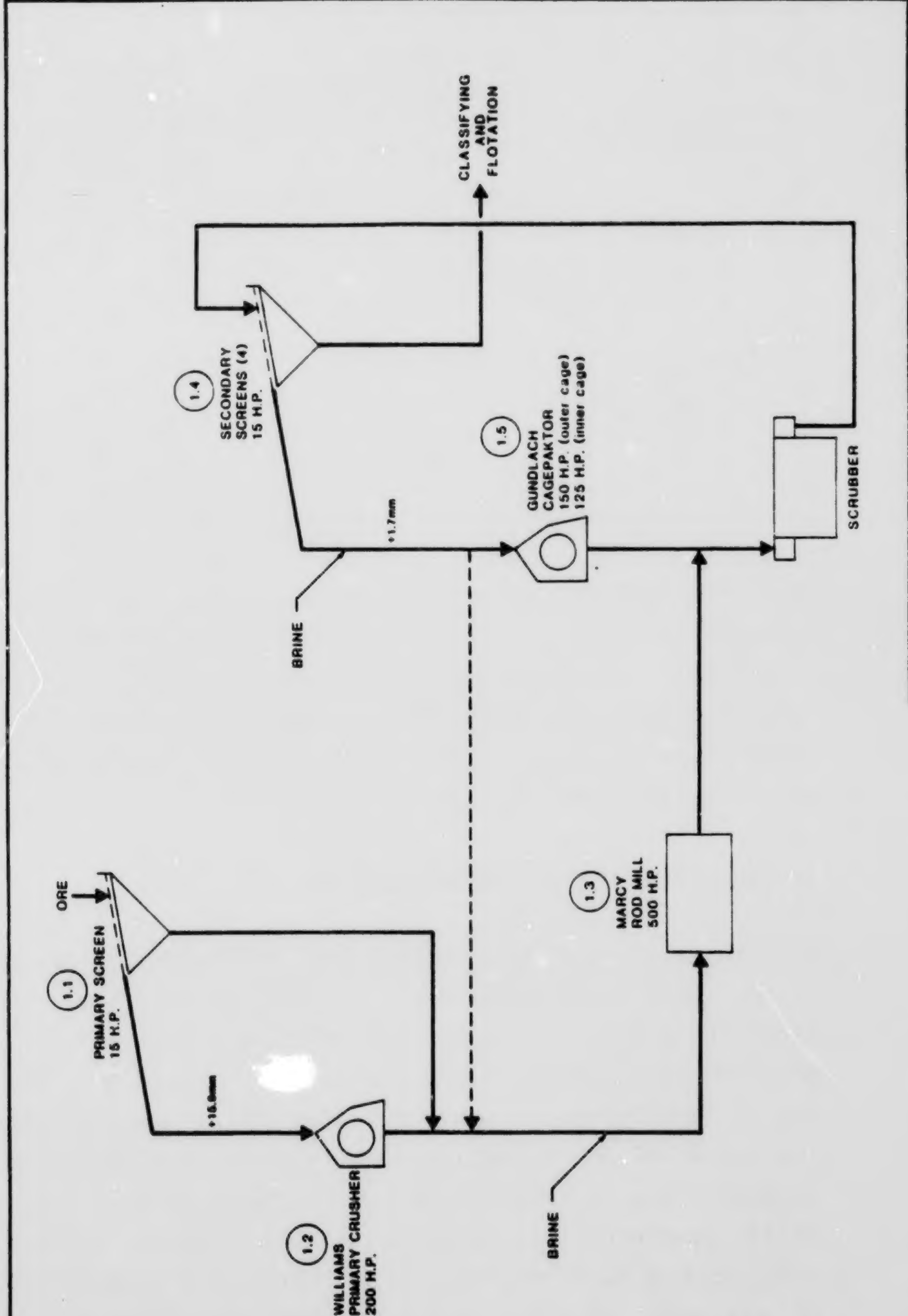
ORE
SCREENING
+16mm
-16mm
CRUSHING
ROD MILL
CRUSHING CAGE PAKTOR
+1.7mm
SCREENING
-1.7mm
SCRUBBING
CLASSIFYING
O/F
CYCLONING
O/F
A
B
A
FLOTATION
PRODUCT WASH
CENTRIFUGING
DRYING
PRODUCT SCREENING
-3.35mm, +850µm
150µm
COMPACTION
PINK PRODUCTS
TAILS THICKENER
TAILS
O/F
SOLUBLE LEACH
SOLUBLE CRYSTALLIZATION
CENTRIFUGING
DRYING
SOLUBLE PRODUCT
B
SLIMES THICKENER
TAILS
O/F
H.G. LEACH
H.G. CRYSTALLIZATION
CENTRIFUGING
DRYING
HIGH-GRADE PRODUCT

2.2 Ore Processing

It is important in potash processing to maintain as large a particle size as possible[4] while still liberating the KCl since fertilizer application requires a relatively coarse product. Also, liberation of sylvite must be sufficient to meet the 95% KCl minimum requirement.

Processing at PCS Cory begins with the mine-run ore passing over a primary scalping screen (Fig. II) with +16 mm material being fed to a 200 HP impact crusher. Approximately 12-15% of the ore is large enough to require primary crushing. The primary screening and crushing operations are dry. The crusher product and primary screen undersize are mixed and, at this point, brine is introduced and the mixture fed to a 500 HP variable speed rod mill. From this stage until final product drying, the Cory mill is wet process.

The rod mill product passes to the primary scrubber which begins the process of removing the clay particles from the crystal surfaces. The removed clay goes into suspension in the brine. This mixture then passes to four secondary wet-screens operating in parallel. The +2 mm oversize is fed to a two concentric squirrel cagepaktor powered by 125 and 150 HP motors on the inner and outer cages, respectively. The cagepaktor product returns to the outlet of the rod mill and thence to the primary classifier in a closed-circuit loop. The option exists for the cage mill to be bypassed with wet-screen which removes the oversize to the rod mill. This is not normally done since overall throughput is severely hampered with the cage mill shutdown. Comminution and associated equipment in the primary circuit are listed in Table 1.


ORE
1.1
PRIMARY SCREEN
15 H.P.
+15.9mm
1.2
WILLIAMS
PRIMARY CRUSHER
200 H.P.
BRINE
1.3
MARCY
ROD MILL
500 H.P.
BRINE
+1.7mm
1.4
SECONDARY
SCREENS (4)
15 H.P.
1.5
GUNDLACH
CAGEPAKTOR
150 H.P. (outer cage)
125 H.P. (inner cage)
SCRUBBER
CLASSIFYING
AND
FLOTATION

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE II
ORE CRUSHING FLOW DIAGRAM

PLANT N° CORY DIVISION
PCS MINING - SASKATOON

PROJECT No. 20010

DRAWN GFJ
DATE 3/04/84
CHECKED DCS
DATE 20/09/84

TABLE 1 - Ore Processing Equipment List

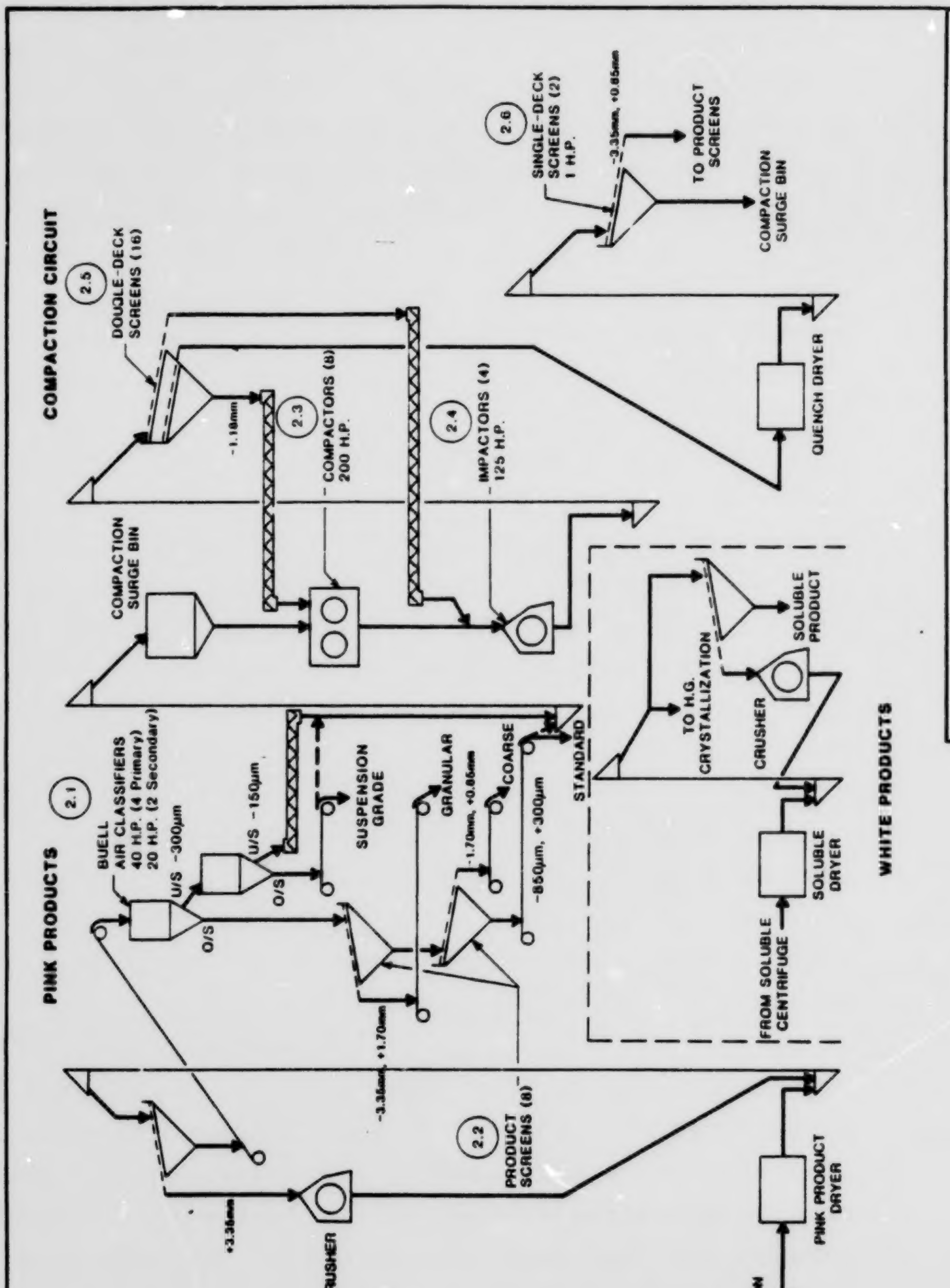
No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR H.P.	MOTOR AMPS
1.1	Primary Screen	15	15
1.2	Primary Crusher - Williams Type K Size #340 Reversible	200	200
1.3	Rod Mill - Marcy 440 V DC 10'10" dia. x 14' Open End	500	1130
1.4	Secondary Screens (4)	15	15
1.5	Cagepaktor - Gundlach 50-2C4R-B Outer Cage Inner Cage	 150 125	 150 125

Note: All motors 550 volt except where noted.

The wet-screen undersize, being the product of the comminution circuit, now passes through various stages of scrubbing, classifying and hydrocycloning to prepare a feedstock for the flotation circuit. The description and operation of these circuits is omitted since they are not directly involved in size reduction.

2.3 Product Screening and Compaction

The product drying, screening and compaction circuits (Fig. III) are involved in processing the "pink" or floated products. The pink cake from the flotation product centrifuges is dried in rotary dryers and passed over a scalping screen with the +3.35 mm oversize being fed to a 25 HP "lumpbreaker" crusher and returned to the screen. The undersize is fed to four primary air classifiers operating in parallel. Air classifying involves passing the feed material down through a cross-flow stream of air with heavier particles passing through the stream


PINK PRODUCTS
COMPACTION CIRCUIT
WHITE PRODUCTS
FROM FLOTATION PRODUCT CENTRIFUGES
PINK PRODUCT DRYER
CRUSHER
+3.35mm
2.2
PRODUCT SCREENS (8)
-3.35mm +1.70mm
2.1
BUELL AIR CLASSIFIERS
40 H.P. (4 Primary)
20 H.P. (2 Secondary)
U/S -300μm
O/S
U/S -150μm
SUSPENSION GRADE
GRANULAR
-1.70mm, +0.85mm
COARSE
-850μm, +300μm
STANDARD
COMPACTION SURGE BIN
2.3
COMPACTORS (8)
200 H.P.
2.4
IMPACTORS (4)
125 H.P.
2.5
DOUBLE-DECK SCREENS (16)
-1.18mm
QUENCH DRYER
2.6
SINGLE-DECK SCREENS (2)
1 H.P.
-3.35mm, +0.85mm
TO PRODUCT SCREENS
COMPACTION SURGE BIN
FROM SOLUBLE CENTRIFUGE
SOLUBLE DRYER
CRUSHER
TO H.G. CRYSTALLIZATION
SOLUBLE PRODUCT

CANADA CEMENT LAFARGE LTD.
MONTREAL

FIGURE III
PRODUCT SCREENING & COMPACTION
FLOW DIAGRAM

PLANT AT CORY DIVISION
PCS MINING-SASKATOON

DRAWN FGM DATE 07/19/83
CHECKED DCS DATE 20/09/84

PROJECT No. 20010

to coarse product and the lighter particles being entrained in the air stream and being subsequently cycloned out as fine product. The "cut-point" is adjusted by changing the air flow. The +300 μm coarse product from the primary air classifiers is fed to four product screens in parallel. The +2.00 mm oversize serves as -3.35 +2.00 mm granular product. The undersize passes to a second set of four product screens in parallel where the +850 μm oversize becomes -2.00 mm +850 μm coarse product. The undersize is -850 +300 μm standard product.

The fine product from the primary air classifier is fed to two secondary air classifiers in parallel. The +150 μm coarse fraction from these classifiers serves as -300 +150 μm suspension product. The fine product from the classifiers is sent to the compaction circuit. The finer standard and suspension products, depending on demand, can also be sent to compaction for size enlargement to make coarser product.

Cory has two compaction circuits, each consisting of four 200 HP compactors in parallel and two 125 HP impact crushers in parallel. Each circuit also has a set of eight vibrating screens in parallel and a rotary quench dryer.

The compaction circuit feed is held in a surge bin and distributed to the roll-type compactors where it is compressed to a high density flake through the application of high pressures on the rolls. This material then passes through the impactors and is fed to the vibrating screens where a -3.35 +1.40 mm mid-fraction is removed. The oversize and undersize return to the impactors and compactors, respectively. The mid-fraction is dried in a rotary quench dryer and fed to two vibrating screens in parallel with the +850 μm oversize going to the product screens and the undersize being returned to the compaction surge bin. Product screening and compaction equipment is listed in Table 2.

TABLE 2 - Product Screening and Compaction

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR	
		H.P.	AMPS
2.1	Buell Air Classifiers		
	Primary (4)	40	40
	Secondary (2)	20	20
2.2	Product Screens (8) 230 V	-	-
2.3	Compactors (8)	200	200
2.4	Compaction Crushers (4) Pennsylvania Type CAL7-38	125	125
2.5	Compaction Double-Deck Screens (16) 230 V	-	-
2.6	Compaction Single-Deck Screens (2) 110 V	3 x 1/3	2

Note: All motors 550 volt except where noted.

With regard to the processing of white products, the cake from the soluble centrifuge is dried in a rotary dryer and passed over a screen with the oversize being fed to a 30 HP "lumpbreaker" crusher and returned to the screen. The undersize goes to product handling and storage as soluble product. The cake from the H.G. centrifuge is dried in a rotary dryer and becomes finished high-grade product.

3. RESULTS AND DISCUSSION

3.1 Ore Processing

3.11 Electrical Measurements

Electrical data obtained during the field work pertaining to ore processing is presented in Table 3. The reported kilowatt data was calculated from observed volt, amp and power factor readings.

TABLE 3 - Ore Processing

(Measurements)

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
1.1	Primary Screen	15	5	5	5
1.2	Primary Crusher	200	160	105	127
1.3	Rod Mill	500	435	326	370
1.4	Secondary Screens (4)	15	4	4	4
1.5	Cagepaktor				
	Outer Cage	150	81	65	73
	Inner Cage	125	53	40	47

The measurements indicate that the primary screen was operating well within its power limit although it produces the entire volume of mill feed. The primary crusher measurements reveal, on average, that the crusher operates within its power capacity although the maximum power draw does approach the limit. However, the measured power factor was very good (near 1) and, with the crusher handling 12-15% of the mill feed presently as compared to 35% in the past, the crusher is not overloaded.

The rod mill electrical measurements indicate that the drive is reasonably loaded on average. The maximum power draw does not present an overload problem since the power factor is high. The kilowatts were calculated treating the drive as direct current, single-phase. The D.C. drive is necessary since some rod mill speed adjustments may be necessary from time to time. The secondary wet-screens are operating well within their power capacity.

Both cagepaktor motors appear to be operating under the same degree of loading according to the measurements. The loading is moderate with even the maximum power draw well below the limit. However, the cagepaktor loading depends entirely on the amount of circulating load in the ciruit. When measured, the power drawn by the cagepaktor was well below installed capacity.

3.12 Flowrates

Stream flowrates for the ore processing circuit were obtained from a material balance carried out previously by the plant staff at Cory and based on a mill ore feed rate of 450 t/h. This exercise had been done to determine the effect of the cagepaktor on the circuit and especially on the rod mill. Prior to the installation of the cagepaktor, the rod mill had operated in closed circuit with the secondary wet-screens and had performed all comminution work in the ore processing circuit after the primary crusher. After the installation, the cagepaktor operates in closed circuit with the wet-screens with cagepaktor and rod mill discharge being fed to the screens. The rod mill now operates in open circuit. However, the cagepaktor can be bypassed for repairs and the rod mill returned to closed circuit.

The primary screen separates out the +16 mm particles in the ore as feed for the primary crusher. The flowrate through the primary crusher was estimated from a typical screen analysis of the ore provided by Cory plant staff and selecting the split at 16 mm determined by linear interpolation. The crusher flowrate was calculated by taking the +16 mm fraction as a percentage of 450 t/h.

Secondary screen and cagepaktor feedrates were used as reported in plant records. The flowrate data is summarized in Table 4.

TABLE 4 - Ore Processing Flowrates

	t/h
Primary Screen	450
Primary Crusher	63.5
Rod Mill	450
Cagepaktor Discharge	260
Wetscreens Undersize	450

3.13 Size Distribution

Size distributions of various streams in the ore processing circuit (Table 5), as with flowrates, were obtained from the Cory Metallurgical Lab reports.

Primary crusher feed was estimated from the reported ore size distribution based on a split at 16 mm.

TABLE 5 - Ore Crushing Circuit - Size Distributions

SIEVE	ORE %	PRIMARY CRUSHER		ROD MILL		CAGEPAKTOR	
Opening	Passing	Feed	Disch	Feed	Disch	Feed	Disch
32.0 mm	100	100					
26.7	92.0	43.0					
18.9	88.0	14.0	100	100			
13.3	83.1		82.3	98.3		100	
9.42	77.2		74.6	94.1	100	98.7	100
6.00	70.8		67.0	86.1	99.0	93.7	99.4
4.75	64.0		60.9	79.3	97.5	82.8	98.5
3.35	56.9		53.3	71.7	94.5	58.9	91.7
2.36	48.9		45.1	63.3	87.1	19.2	78.6
2.00	41.1		37.2	54.7	81.4	5.8	55.2
1.40	34.1		29.8	46.7	70.3	2.8	39.9
850 µm	28.7		23.8	40.5	60.7	1.8	30.1
600	22.8		18.0	33.7	49.1	1.2	20.6
500	18.1		13.4	28.3	39.9	0.9	15.2
300	13.8		9.5	23.4	31.1	0.7	10.8
250	10.3		6.6	19.4	23.4	0.7	8.2
150	7.2		4.5	15.7	13.7	0.7	6.3
106	4.8		3.1	11.8	11.3	0.7	4.5

Rod mill feed, being a combination of primary screen undersize and primary crusher discharge, is shown to be finer than primary crusher discharge. This implies the relatively high fineness of primary screen undersize compared to primary crusher discharge and confirms the presence of the significant amount of fines in the ore from the mine.

Comparison of rod mill and cagepaktor feeds reveals that most of the fines have been removed by the secondary screens. Cagepaktor discharge fineness is comparable to rod mill discharge fineness in the larger sizes but drops off more rapidly in the smaller sizes. This is at least partly due to the fact that cagepaktor feed has passed over the secondary screens, whereas the rod mill receives fines which are already present in the ore.

3.14 Grindability

The results of grindability testing of a sample of rod mill feed are summarized as follows:

Bond Work Index : 13.55 kWh/Ton
Hardgrove Grindability Index : 55
Bond Work Index Calculated : 11.34 kWh/Ton

These results indicate a material that is difficult to grind. However, lab grindability results may be overstated because, under the test conditions, the material is ground significantly finer than actually occurs in the process. For example, in the plant process, the material is ground to less than 10% passing 100 µm, while the grindability test reduces the material to 75 µm.

The nature of potash ore is such that the sylvite and halite crystals are separated at a certain size depending on the ore. The objective of comminution is to grind sufficiently fine to produce individual crystals and meet the 2.00 mm minimum fineness for flotation. At this size requirement, much of the comminution work goes towards separating the individual crystals within the mass. The forces holding the crystals together are small since crystal surfaces are well defined and particles of clay are located between crystals. However, at minus 75 µm, more energy is being spent to break up individual crystals where the binding forces are greater. Therefore, the Bond Grindability test, as conducted, may not relate well to what is actually happening in the process, indicating a much harder material than seems to be observed in practice.

3.15 Energy Consumption

Power Consumption data pertaining to the ore processing circuit (Table 6) shows that the consumption of electrical energy is quite small overall. The three comminution devices, impactor, rod mill and cagepaktor, use 97% of the circuit's energy demand. The two screening steps account for the remainder.

TABLE 6 - Potash Ore Comminution
Specific Power Consumption

Flowrate: 450 t/h

	kWh/tonne	%
Comminution	1.36	97
Auxiliaries	0.04	3
TOTAL	1.40	100

Comminution energy in the ore processing circuit is low for two reasons. The ore is easy to grind and the degree to which the ore must be ground is moderate.

3.2 Product Screening and Compaction

3.21 Electrical Measurements

Electrical results (Table 7) for the final pink product classifying phase of the process show that, for this stage, the main electrical power draw is by the eight compaction units. Although there is over 200 HP installed in the Buell air classifier units, the measurements show that the motors are operating at about half load, thereby reducing the overall power draw. The energy consumption of the classifiers, in the form of circulating air fans, is quite steady with little fluctuation in kilowatts.

The compaction units, each rated at 200 HP, were shown to be well loaded with good power factor. Despite the large power draw of the compactors, there is little fluctuation, due to the steady feed rate of each unit.

TABLE 7 - Product Screening and Compaction

(Measurements)

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
2.1	Buell Air Classifiers				
	Primary (4)	40	15	15	15
	Secondary (2)	20	6	6	6
2.2	Product Screens (8)	-	3	3	3
2.3	Compactors (8)	200	140	140	140
2.4	Compaction Crusher (4)	125	40	28	33
2.5	Compaction Double-Deck Screens (16)	-	3	3	3
2.6	Compaction Single-Deck Screens (2)	3 x 1/3	1	1	1

Four compaction crushers or impactors immediately follow the compactors in the process flow. The loading of the impactor motors is quite low, averaging about a third of capacity and a maximum power draw less than half capacity. The measurements also indicate some fluctuation in kilowatts drawn by the impactors is caused by the introduction of larger pieces of feed.

3.22 Flowrates

The pink product flowrate is calculated from the mill ore feed rate based on a 3:1 ore to pink product yield ratio. This production rate is taken as the throughput of the Buell air classifiers.

Flowrates in the compaction circuit are based on a circuit throughput rate of 7-8 t/h per compactor as indicated during the field work. Since this throughput rate agrees closely with design estimates, remaining compaction circuit flowrates are taken from design figures, allowing for minor corrections to close the mass balance. A circulating load of approximately 300% exists in the compaction circuit. It is split into two parts: an undersize return stream to the compactors and an oversize return stream to the impactors. The individual flowrates for the oversize and undersize fractions of the circulating load are nearly the same. The compaction circuit throughput rate is based on the indicated throughput rate per compaction unit with all compactors operating.

The compaction circuit product is fed to the product screens and can end up in any of the products. Most of the pink product demand is for the granular and coarse products. The flowrate data is summarized in Table 8.

TABLE 8 - Product Screening & Compaction Flowrates

	t/h
Air Classifier Feed	150
Compactor Output	19.4
Impactor Output	58.8
Compaction Circuit Output	58.1
Pink Products	150

3.23 Size Distribution

Particle size information of various process streams in the product screening and compaction department is expressed as range of size of particles for the stream in question.

The feed to the compaction circuit is -150 μm from the second stage Buell air classifiers, although larger if standard or suspension material is directed to compaction. An important feature of the compaction circuit is that, of the material processed through the impactors, only the -3.35 +1.40 mm mid-fraction is selected for drying. The oversize returns for size reduction and the undersize returns for size enlargement at the compactors. Any -850 μm material generated in the mid-fraction by drying and handling is screened out and again returned to the compactors. As mentioned earlier, the material must be in a specific size range before becoming final product.

3.24 Energy Consumption

Specific power consumption for compaction and screening of pink products (Table 9) includes electrical energy consumed by air classifiers and product screens as well as screens in the compaction circuit. The results for the compaction circuit are included for comparative purposes but are not regarded as comminution.

TABLE 9 - Compaction and Screening Specific Power Consumption

Flowrate: 150 t/h

	kWh/tonne	%
Comminution	0.88	46
Auxiliaries	1.05	54
TOTAL	1.93	100

The proportion of total specific energy represented by comminution energy in this stage of processing is relatively low. Comminution energy represents less than half the total since the four compaction crushers are not heavily loaded and operate in conjunction with the air classifiers and numerous sets of screens.

Total and comminution energy consumption for pink products is given in Table 10. The reported energy is cumulative, representing consumption over all stages of the process where comminution and classifying occur.

TABLE 10 - Pink Products
Cumulative Power Consumption

Flowrate: 150 t/h

	kWh/tonne	%
Comminution	4.96	81
Auxiliaries	1.17	19
TOTAL	6.13	100

Pink Products
Compaction Power Consumption
7.47 kWh/tonne

Cumulative energy is calculated allowing for the 3:1 yield ratio at flotation. The total energy is low, at just over 6 kWh/tonne. Comminution energy represents a much greater portion of the total than at compaction and screening alone since comminution accounted for a very high proportion of energy consumed in primary ore processing. Nonetheless, the percentage of cumulative auxiliary energy is significant, representing several screening and classifying steps.

Finally, electrical consumption by compaction is calculated and reported, distributed over pink products. This energy is significant, being greater than cumulative comminution and auxiliary energy and 50% greater than cumulative comminution energy alone.

4. CONCLUSION AND RECOMMENDATIONS

Overall, the comminution and associated energy required to process potash ore into pink products at Cory is relatively low. Comminution occurs chiefly for manufacturing pink products with little comminution energy required for white products. Compaction is a considerable consumer of energy in pink product manufacture, actually being greater than comminution and auxiliaries combined. The energy consumption reported is averaged over all pink products, despite the fact that the production rate for individual pink products varies according to demand.

The primary ore crushing circuit appears to be making efficient use of energy for comminution with a high throughput of 450 t/h. The combined energy required for comminution and screening is 1.4 kWh/tonne, although this low value is offset somewhat by the fact that roughly three tonnes of ore must be processed through the primary circuit for each tonne of finished material produced.

Particle size distribution data indicate that much of the very fine particles is present in the ore received at the mill because considerable size reduction takes place during mining. The cagepaktor appears to produce fewer fines than the rod mill. Fines generation at the rod mill depend on the mill loading and whether it is operated in open or closed circuit. It is desirable to prevent very fine particles from being produced since they have a tendency to be entrained to slimes handling. Any improvements to the primary circuit from the present arrangement would be towards improving throughput and would be expected to have only a small effect on energy consumption.

The final pink product comminution energy consumption was calculated to be about 6.1 kWh/t with another 7.5 kWh/t required for compaction. The compactors represent the greatest energy consumption with 8 units, each rated at 200 HP. The compaction step represents a high energy consumption due to the nature of the operation with the rollers acting under high pressures. Also, the throughput of each compactor is relatively small for the power required.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

General

Potash is the generic term used for a range of potassium bearing minerals, ores and refined products. Potassium, along with nitrogen and phosphate is one of the three essential plant nutrients. Potash is used mainly as a fertilizer and the major markets are in the developed countries.

The principal product is potassium chloride (KCl), commonly called "muriate". It accounts for 80% of the world potash production and is the sole Canadian potash product. The other salts which are marketed are potassium sulfate (K_2SO_4: U.S.A., U.S.S.R., Europe) and potassium magnesium sulfate (K_2SO_4, $2MgSO_4$: U.S.A., West Germany).

The U.S.S.R. is the largest producer and accounted for about 35% of the estimated world production in 1982. Canada follows with 21% of the world production. Potash production volumes since 1977 of the three major producers are shown in Table 1.

TABLE 1 - U.S.S.R., Canada, U.S.A. and World Potash Production 77-82[5,8]

	(thousands of tonnes K_2O equivalent)					
	1977	1978	1979	1980^p	1981^e	1982^e
U.S.S.R.	8 347	8 193	6 635	8 064	8 350	8 600
Canada	5 764	6 340	7 074	7 532	6 815	5 208
U.S.A.	2 229	2 253	2 235	2 239	2 156	1 782
Total World	25 252	26 113	25 677	27 673	27 357	24 729

^{p} Preliminary
^{e} Estimate

The major identified world potash resources are listed in Table 2. They represent several hundred years of consumption at current rates of exploitation.

TABLE 2 - Identified World Potash Resources[7]

	Million tonnes of K_2O
Canada	74 000
U.S.S.R.	55 000
U.S.A.	6 000
World	151 000

These salts are mined from marine chloride evaporate deposits (85% of the world production in 1975) from natural brines. The three predominant minerals which occur in Western Canadian potash bearing zones are shown in Table 3.

TABLE 3 - Western Canadian Potash Ore Composition

Mineral	Chemical Composition	Concentration in Ore (%)
Halite	($NaCl$)	40 - 60
Sylvite	(KCl)	35 - 50
Carnallite	($KCl.MgCl_2.6H_2O$)	0 - 6
Insolubles	---	2 - 8

The insolubles include clay minerals, anhydrite, dolomite and calcite.

The ore is a "mechanical" mixture, in that the sylvite and halite are present as individual crystals and can be separated by breaking the total mass down to a maximum size of 3 to 12 mm, depending on the ore. The clay adheres to the surface of the crystals and is removed by washing or "scrubbing".

Sylvite has a vitreous luster, is very plastic under pressure and ranges in colour from clear to brick red. The colouration is due to impurities.

The Saskatchewan potash ore is located between 900 and 1000 meters beneath the surface in a seam which is flat and is 3 meters thick throughout much of its area.[9] The ore is mined by continuous borers and transported to the surface by hoist through vertical shafts.

Processing and Products

Sylvinite ores - mixtures of sylvite and halite - are commonly beneficiated by froth flotation in saturated brine solutions. The processing consists of grinding, desliming, flotation and drying circuits.

The ore is crushed using impact crushers and roll mills operating in closed circuit with several sets of screens. The newer wet impact type crushers enable an earlier slime wetting and liberation stage which keep plants cleaner.

Desliming is the next step. The objective is to remove the insolubles which reduce recovery efficiency during flotation. Sized ore in a saturated $NaCl-KCl$ solution is agitated in a series of scrubbers. The fine insolubles are liberated from the sylvite and halite crystals and are separated as a tailing fraction using classifiers and hydroclones.

Deslimed ore is mixed with an amine which acts as a flotation agent and adheres only to the potash particles. Then it is pumped into the flotation cells where agitation with air and additives allows the potash to be floated off as a concentrate, while the halite is pumped to waste.

Fine and coarse feeds are commonly conditioned separately. At this stage, some fine salt is carried over with the rougher concentrate despite high flotation efficiency. One way to eliminate that fine salt is to clean the coarse concentrate by screening out the fines while fine rougher concentrate is upgraded in a cleaner flotation stage.

A crystallizer circuit is used to give a high purity product by a solution process from several product streams (10-25% of plant product) that cannot be upgraded by physical methods.

Screen bowl centrifuges are used to debrine the crystallizer and flotation product slurries. The debrined materials are dried in rotary or fluidized-bed dryers.

At the end of the drying circuit, a set of screens is used to size the products into the different grades (standard, suspension, coarse). The fourth product, granular, is produced by compaction of standard and suspension material. Crystallizer products are screened separately to produce a white soluble material and a refined material.

The process involves brine recovery circuits to decrease losses of potash.

The different commercial products are used as follows:

- **Standard** and **suspension** are used primarily in granulation plants. They are mixed with given amounts of nitrogen and phosphate, then granulated to give a blended fertilizer.

- **Coarse** and **granular** are involved in bulk blending processes. Standard, coarse and granular can also be used in direct application.

- **Soluble** is used for liquid mixed fertilizers and chemical industry.

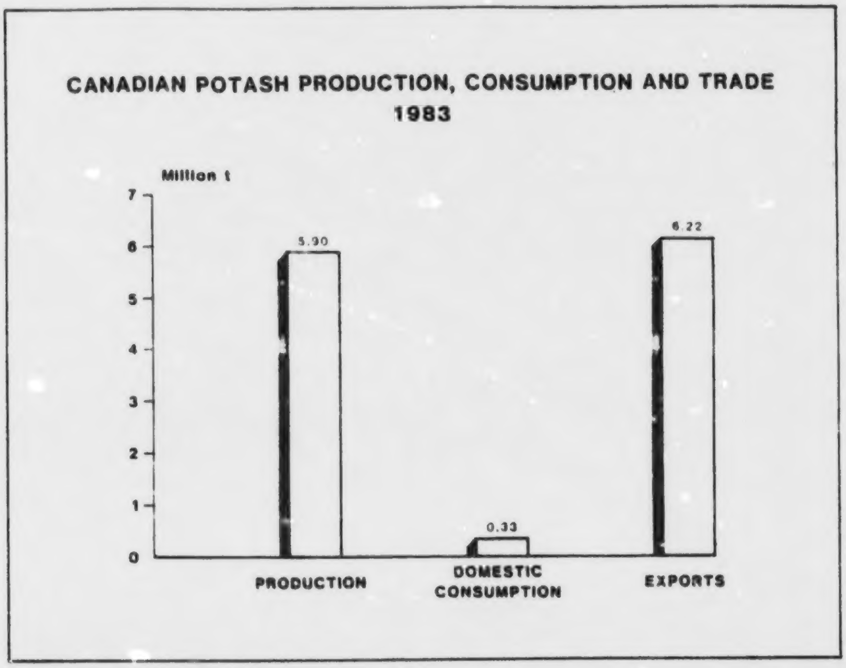
- **Refined KCl** is used in industrial applications.

The Canadian Industry

Potash was first discovered in Canada in the early 1940's while drilling for oil in Saskatchewan. The first potash was shipped in 1959 and Canada became the world's second largest producer in 1968. In 1979, Canada accounted for about 39% of the international potash trade.

Canada exports 95% of its production. About 70% of the exports go to the United States. The production volumes in 1983 are shown in the following diagram.

FIGURE I - Canadian Production Volumes 1983[2]
(in thousand tonnes K_2O equivalent)



Source: Canadian Mining Journal, February 1984.

Location of potash mines and capacity projections are shown in Table 4.

TABLE 4 - Potash Mines - Capacity Projection (000 tonnes K_2O Equivalent)[2]

Company/Location	1982	1983	1984	1985	1986	1987	1988	1989	1990	Remarks
PCS	490	-	-	-	-	-	-	-	-	
- Allan (60%)	490	490	490	655	655	655	655	655	655	Not a firm commitment. Grades: granular, coarse, standard, soluble, suspension and refined.
- Bredenbury	-	-	-	-	655	1310	1960	1960	1960	Mid-1986, earliest target.
- Cory	830	830	830	950	1090	1090	1090	1090	1090	Not a firm commitment. Grades: granular, coarse standard, soluble, suspension and refined.
- Esterhazy (25% of IMCC)	585	585	585	585	945	945	945	945	945	Put in abeyance due to crisis. Grades: granular, coarse, standard, soluble, suspension and refined.
- Lanigan	830	830	1285	1740	1740	1740	1740	1740	1740	Grades: granular, coarse and standard.
- Rocanville	1090	1090	1090	1090	1090	1090	1090	1090	1090	Grades: granular, blend, coarse, standard.
CCP: Viscount	815	815	815	815	815	815	815	815	815	Two grades of products: standard, and granular.
Cominco Ltd., Vanscoy	600	655	655	655	655	655	655	655	655	Three grades of products: standard, granular and coarse.
IMCC, Esterhazy	1750	1750	1750	1750	2110	2110	2110	2110	2110	Conjectural - Not a firm commitment.
Kalium Chemicals Belle Plaine	1055	1055	1055	1055	1055	1055	1055	1055	1055	Grades: standard, coarse, granular and fine soluble.
PCA, Saskatoon	440	635	635	635	635	635	635	635	635	
Can. Dev. Corp. Allan (40%)	325	325	325	435	435	435	435	435	435	Not a firm commitment.
Total Saskatchewan	8680	9060	9505	10365	11880	12535	13185	13185	13185	
Denison, N.B.	-	-	100	400	765	765	765	765	765	Company has to make a decision on whether to proceed with production.
PCA, Sussex, N.B.	-	200	400	545	545	545	545	545	545	Expansion after 1985 possible.
IMCC, Man.	-	-	-	-	-	100	545	1090	1090	Conjectural start-up between 1987 and 1989.
Total Canada	8680	9260	10005	11310	13190	13945	15040	15835	16085	

The breakdown of the Canadian potash production by product in 1981 was:

TABLE 5 - 1981 Canada, Potash Production Breakdown by Product

Product	%
Coarse	36.6
Standard (includes suspension)	28.5
Granular	23.9
Soluble	10
Refined KCl	1

Source: Potash and Phosphate Institute

The typical chemical analysis of processed muriate of potash (KCl) as it is marketed in Canada is shown in Table 6.

TABLE 6 - Chemical Analysis of Muriate of Potash[3]

Compound	Percent
K	50.5
Mg	0.17
Ca	0.02
Na	1.05
Cl	47.86
SO_4	0.04
Insoluble	0.30

Potash is graded chemically according to a standard known as "potassium oxide equivalent (K_2O)". For many years it was thought that the potassium oxide was the key factor in fertilizers and, although this is no longer believed, it remains a unit of measure in potash trade (1.0% K is equivalent to 1.2046% K_2O).

Potash is also classified according to particle size. Products with higher potash grades and coarser particles are more desirable. The grade of pure muriate is 63.2% K_2O equivalent.

Potash Corporation of Saskatchewan, Cory Division, manufactures basically two types of products; floated "pink" and crystallized "white". The pink products are classified by screening into four grades. The crystallized products are "soluble" and "refined". The soluble product is derived by treating overflow brines chiefly from tails and slimes thickeners. The refined product is 99.95% KCl and is manufactured by subjecting a portion of soluble product to a second crystallization process.

The characteristics of the different commercial potash products are shown in Table 7.

TABLE 7 - Commercial Potash Products[7]

TREATMENT	PRODUCT	K_2O CONTENT %	APPROXIMATE PARTICLE SIZE RANGE mm
Flotation (Pink)	Granular	61	3.4-0.8
	Coarse	61	2.4-0.6
	Standard	61.51	1.7-0.2
Crystallization (White)	Soluble	62	0.4-0.15
	Suspension	61	0.4-0.075
	Refined KCl	63	fine

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SILICA

PROCEDE Plastiflex R PROCESS
MONTREAL, QUEBEC

THE SILICA INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
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TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. THE SILICA INDUSTRY 2 - 3

3. PROCESS DESCRIPTION 4 - 14

   3.1 Silica Process Flow 4
   3.2 Ore Crushing and Drying 4
   3.3 Primary Grinding and Classification 8
   3.4 Flotation 11
   3.5 Fine Grinding 11

4. RESULTS AND DISCUSSIONS 15 - 19

   4.1 Ore Crushing and Drying 15

      4.11 Power Demand Estimates 15
      4.12 Specific Energy Consumption 15

   4.2 Primary Grinding and Classification 16

      4.21 Power Demand Estimates 16
      4.22 Specific Energy Consumption 17

   4.3 Fine Grinding 17

      4.31 Power Demand Estimates 17
      4.32 Grindability 17
      4.33 Specific Energy Consumption 18

   4.4 Products Specific Energy Consumption 18

5. CONCLUSIONS AND RECOMMENDATIONS 20

APPENDIX - Industry Review

   1. General Information
   2. Product Characteristics
   3. Quality Criteria

REFERENCES

1. INTRODUCTION

Under the general title of "Energy Conservation in the Industrial Minerals Processing Sector - Comminution", Phase I of the project deals with plant studies to develop a data base. Phases II and III will attempt to reduce the amount of energy used in comminution.

The plant studies aim at establishing the comminution requirements and classification characteristics for some industrial minerals. Product specification must be considered. The plant studies involve the description of typical operations for each industrial mineral and the compilation of data among which are included the following parameters:

- Operating conditions
- Production rate, flowrates and material balance
- Particle size distributions
- Direct energy consumptions

The data on these parameters is compiled at each comminution stage and the variability of measurements reported.

The report introduces briefly the Canadian silica industry. A description follows of typical comminution processes used in the silica industry. Power level estimates and energy consumption data are then reported and discussed. Conclusions end the body of the report.

For readers who are unfamiliar with the silica industry, an appendix entitled "Industry Review" is added.

2. THE SILICA INDUSTRY

The Canadian silica industry is mainly based in Quebec and Ontario with about two thirds of the production being generated in these two provinces. Some production is done in every province, except Prince Edward Island.

Historically, consumption has always been greater than production and imports cover generally about 30% of consumers' needs. Exports are small, representing around 5% of imports. Typically, the annual consumption is over 3 million tonnes while production is over 2 million tonnes.

The main consuming industries for silica are as follows:

- The ferrous industry using foundry sand.
- The glass making industry using silica.
- The non-ferrous metallurgical industry using lump silica as smelter flux.
- The ceramic industry using finely ground silex grade silica.
- The filler industry using extremely finely ground silica.

The first three industries consume up to 75% of total consumption in relatively equal shares while the rest is distributed over a multitude of uses, the major ones being cement making, concrete products, abrasives, silicon and silicon alloys, ceramic products, fillers and extenders.

Canada imports mainly high-grade silica for use in glass manufacturing, and round-shaped sand suitable for foundry castings. These imports come almost entirely from the United States where many producers are well located, close to the border, and are advantaged by low transportation costs and very pure deposits requiring only simple, low-cost mining and processing.

For more details, see Appendix.

3. PROCESS DESCRIPTION

3.1 Silica Process Flow

A typical silica processing flow sheet for a quartzite ore is shown in Figure I. It consists of a three-stage crushing circuit for ore preparation, a primary grinding (rod mill) and classification circuit to produce various sizes of silica sand, a flotation circuit to produce a flint grade and fine grinding circuit (pebble mill) to produce 75 and 45 µm silex grade products.

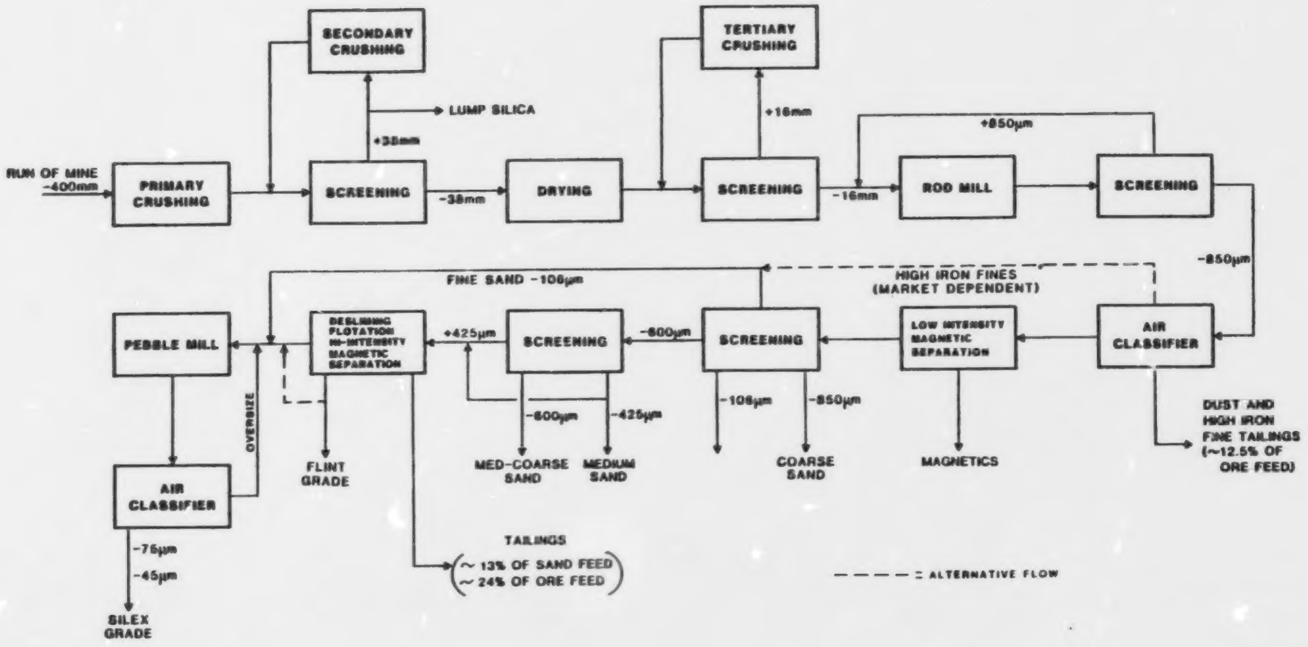
At given points of the flow sheet, equipment such as screens, air classifiers and low and high intensity magnetic separators are used to size and remove iron-containing particles. The flint grade requiring desliming and flotation is not detailed because no further comminution takes place in generating this product.

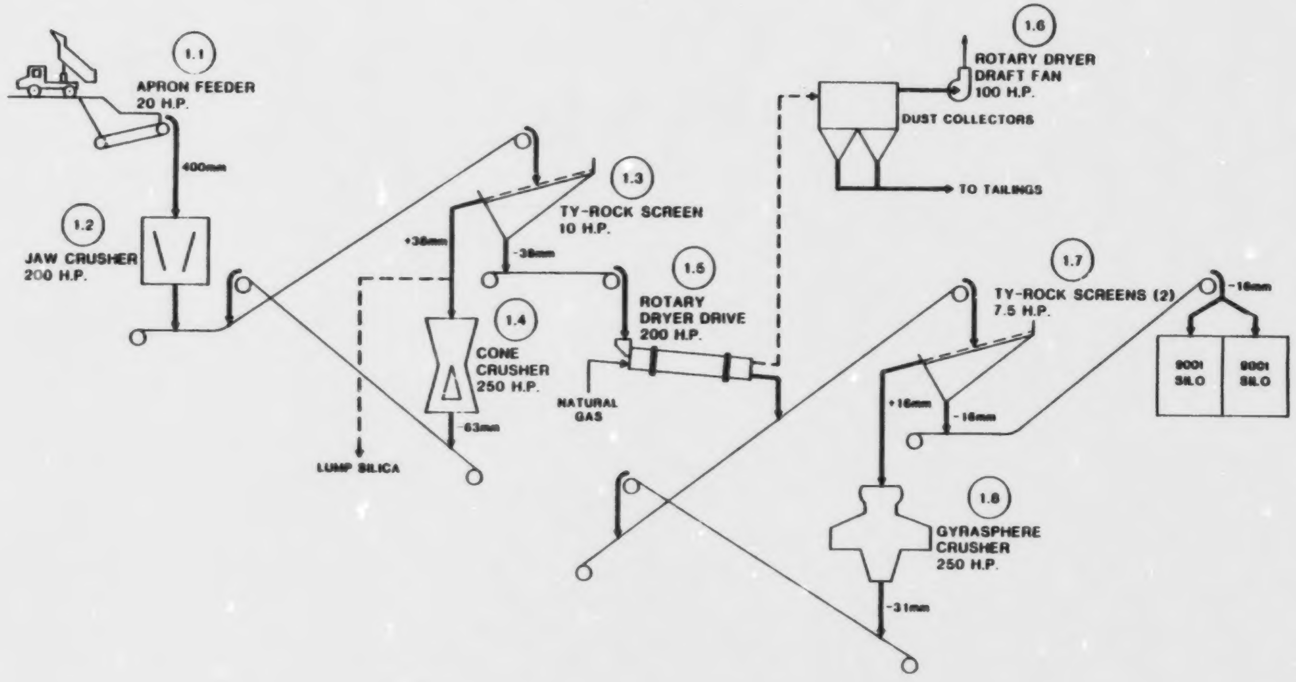
3.2 Ore Crushing and Drying

Figure II illustrates a typical ore crushing and drying circuit. A typical list of equipment with motor electrical data is given in Table 1. Estimated average power demand values are immediately added as no field work and actual plant measurements could be made in an operating environment.

The crushing circuit is usually located at the quarry site and operates on one shift a day, five days a week. The average production rate for the circuit envisaged here is estimated at 135 t/h.

Figure I - TYPICAL SILICA PROCESS FLOW SHEET


RUN OF MINE
-400mm
PRIMARY CRUSHING
SECONDARY CRUSHING
SCREENING
+38mm
LUMP SILICA
-38mm
DRYING
TERTIARY CRUSHING
SCREENING
+16mm
-16mm
ROD MILL
SCREENING
+850μm
-850μm
AIR CLASSIFIER
DUST AND HIGH IRON FINE TAILINGS (~12.5% OF ORE FEED)
HIGH IRON FINES (MARKET DEPENDENT)
LOW INTENSITY MAGNETIC SEPARATION
MAGNETICS
SCREENING
-106μm
-850μm
COARSE SAND
FINE SAND -106μm
-600μm
SCREENING
-600μm
-425μm
MED-COARSE SAND
MEDIUM SAND
+425μm
DESLIMING FLOTATION HI-INTENSITY MAGNETIC SEPARATION
FLINT GRADE
TAILINGS
(~ 13% OF SAND FEED
~ 24% OF ORE FEED)
PEBBLE MILL
OVERSIZE
AIR CLASSIFIER
-75μm
-45μm
SILEX GRADE
- - - - : ALTERNATIVE FLOW


1.1
APRON FEEDER
20 H.P.
400mm
1.2
JAW CRUSHER
200 H.P.
1.3
TY-ROCK SCREEN
10 H.P.
+38mm
-38mm
1.4
CONE
CRUSHER
250 H.P.
-63mm
LUMP SILICA
1.5
ROTARY
DRYER DRIVE
200 H.P.
NATURAL
GAS
1.6
ROTARY DRYER
DRAFT FAN
100 H.P.
DUST COLLECTORS
TO TAILINGS
1.7
TY-ROCK SCREENS (2)
7.5 H.P.
+16mm
-16mm
-16mm
900t
SILO
900t
SILO
1.8
GYRASPHERE
CRUSHER
250 H.P.
-31mm

NOTE: 2 Dust Collectors (not shown) 2 X 50 H.P.

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FIGURE II
CRUSHING AND DRYING
TYPICAL FLOW DIAGRAM

PLANT N°

PROJECT No. 20010

TABLE 1 - Crushing and Drying - Typical Equipment List
Electrical Data and Estimated Power Demand

		MOTOR* HP	POWER DEMAND kW
No.	EQUIPMENT		AVG.
1.1	Apron Feeder	20	8
1.2	Jaw Crusher - 4160V	200	50
1.3	Ty-Rock Screen - 5' x 12'	10	4
1.4	5½ ft Cone Crusher - 4160V	250	100
1.5	Rotary Dryer Drive - 4160V	200	75
1.6	Rotary Dryer Draft Fan	100	58
1.7	Ty-Rock Screen - 4' x 12' (2)	7	3
1.8	Gyrasphere Crusher - 4160V	250	150
1.9	Crushing Plant Dust Collector	50	29
1.10	Screening Plant Dust Collector	50	33

* All motors 550V unless noted.

An apron feeder feeds minus 400 mm ore to a primary jaw crusher powered by a 200 HP motor. The product is screened with the undersize minus 38 mm fraction going to the dryer. The oversize is reduced to minus 63 mm in a secondary cone crusher closing the circuit with the 38 mm screen. A 250 HP motor powers the cone crusher. The secondary crusher product joins with the primary crusher product, creating an estimated combined flow of 225 t/h and a circulating load of about 60-65%.

The installed power for the dryer drive and the draft fan totals 300 HP. After drying, the ore proceeds to a second closed circuit consisting of two screens and a gyrasphere crusher, the latter being powered by a 250 HP motor. The screens extract the minus 16 mm finished product from the combined dryer discharge and circulating load. The plus 16 mm oversize fraction is reduced to minus 31 mm by the tertiary gyrasphere crusher. The circulating flow would be 270 t/h.

The crushing circuit is equipped with two dust collectors, each with a 50 HP fan.

3.3 Primary Grinding and Classification

Primary grinding is effected in a rod mill circuit closed by a series of screens with an 850 μm aperture. The ground product is upgraded by removing abraded iron by magnetic air classification and separation before final screen classification into various size fractions ranging from 850 to 106 μm. A typical chemical specification for glass sand manufacture would be about 99.6% SiO_2, 0.15% Al_2O_3, 0.03% Fe_2O_3 and consistently low CaO and MgO.

A typical process flow sheet is depicted in Figure III and a typical equipment list with motor electrical data is given in Table 2. Estimated power demand values are shown.

TABLE 2 - Primary Grinding and Classification
- Typical Equipment List: Electrical Data & Estimated Power Demand

No.	EQUIPMENT	MOTOR* HP	POWER DEMAND kW AVG.
2.1	Rod Mill - 11.5' x 14' - 4160V	500	300
2.2	Ty-Speed Screen - 4' x 10' (8)	7	3
2.3	Vari-Speed Whizzer Class. - 500 DC	50	25
2.4	Classifier Draft Fan	250	170
2.5	Derrick Screen - 4' x 10' (2)	2	1
2.6	Derrick Screen - 4' x 10' (2)	2	1
2.7	Dust Collector	200	120

* All motors 550V unless noted.

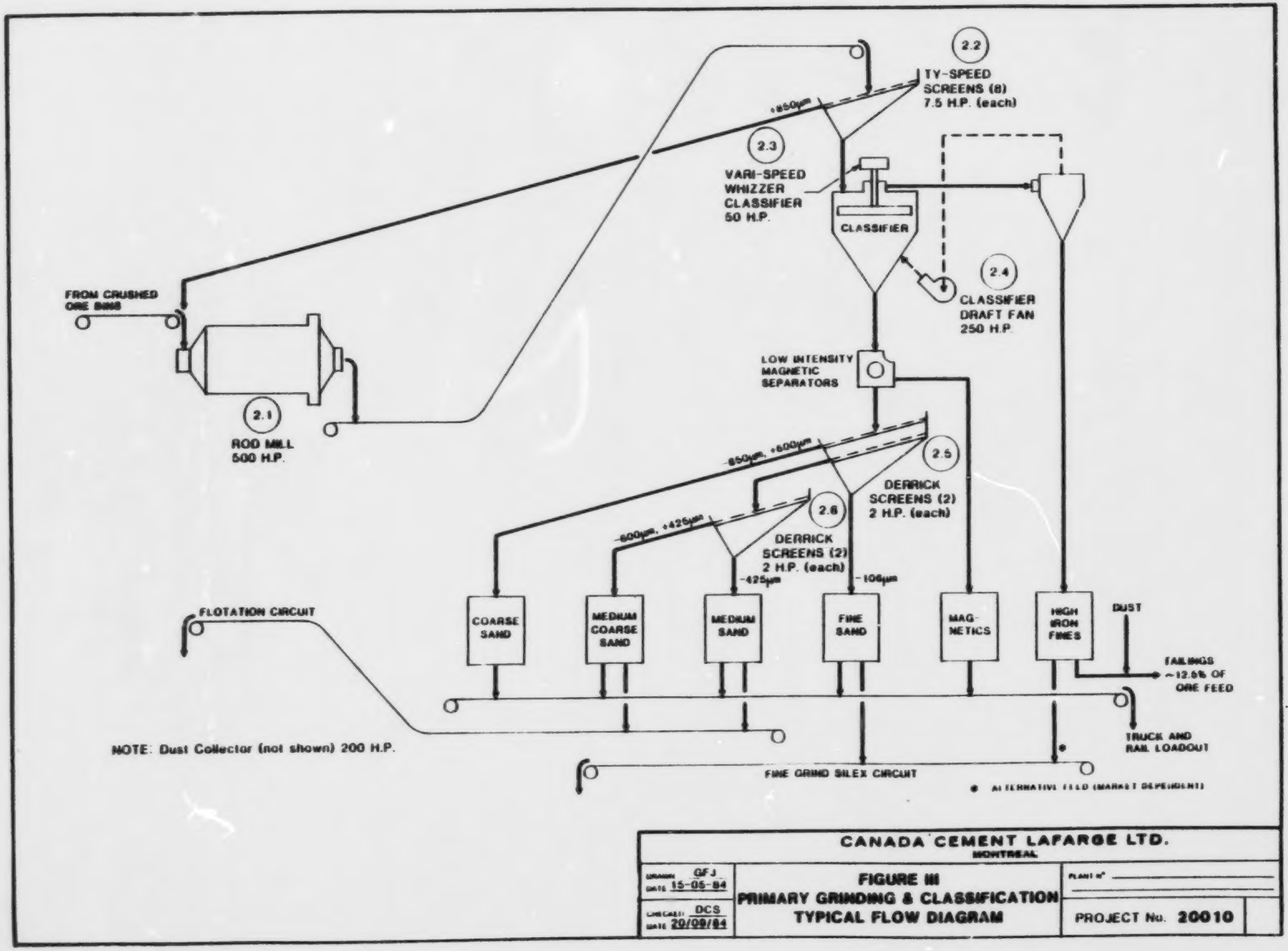
FROM CRUSHED ORE BINS
2.1
ROD MILL 500 H.P.
2.2
TY-SPEED SCREENS (8) 7.5 H.P. (each)
+850µm
2.3
VARI-SPEED WHIZZER CLASSIFIER 50 H.P.
CLASSIFIER
2.4
CLASSIFIER DRAFT FAN 250 H.P.
LOW INTENSITY MAGNETIC SEPARATORS
2.5
DERRICK SCREENS (2) 2 H.P. (each)
-850µm, +600µm
2.6
DERRICK SCREENS (2) 2 H.P. (each)
-600µm, +425µm
-425µm
-106µm
COARSE SAND
MEDIUM COARSE SAND
MEDIUM SAND
FINE SAND
MAG-NETICS
HIGH IRON FINES
DUST
TAILINGS ~12.5% OF ORE FEED
TRUCK AND RAIL LOADOUT
FLOTATION CIRCUIT
FINE GRIND SILEX CIRCUIT
*
* ALTERNATIVE FEED (MARKET DEPENDENT)
NOTE: Dust Collector (not shown) 200 H.P.

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FIGURE III
PRIMARY GRINDING & CLASSIFICATION
TYPICAL FLOW DIAGRAM

PLANT N°

PROJECT No. 20010

The circuit operates 24 hours a day and the average sand production rate, including saleable magnetics, is estimated at 35 t/h from an ore feed rate of 40 t/h, thus generating about 12.5% tailings of high iron fines and dust. Depending on market requirements, the iron fines are sometimes up-graded by high intensity magnetic separation, or finely ground and classified, or sold without further treatment.

An 11.5' diameter by 14' grate discharge rod mill, powered by 500 HP, is used to generate 40 t/h of minus 850 µm product. The circulating load is estimated at 200%. The ground product is then fed to a vari-speed whizzer classifier having an external draft generated by a 250 HP fan to remove the fines containing up to 0.6% Fe_2O_3. Low intensity magnetic separators complete the sand up-grading by recovering some of the abraded iron added during milling with steel rods.

Ready for classification, the sand is screened on two double-deck screens having top and bottom apertures of 600 and 106 µm, respectively. The oversize and undersize make two sand products, coarse (-850, +600 µm) and fine (-106 µm), while the mid or medium fraction is separated by a set of two single-deck screens (425 µm aperture) in two other sand products, medium-coarse (-600, +425 µm) and medium (-425, +106 µm). Dust control is effected by the use of a collector equipped with a 200 HP fan.

These sand products are sold as is, or can be processed further, the medium-coarse and medium sand going to flotation to produce the higher purity flint grade, and the fine sand, to the pebble mill circuits to produce either 75 or 45 µm silex grades.

3.4 Flotation

A sized sand can be upgraded to flint grade, i.e., containing less than 0.02% Fe_2O_3, by processing through a circuit illustrated in Figure IV and comprising three stages of beneficiation: attrition scrubbing, flotation and magnetic separation.

Attrition scrubbing releases the clay minerals from the silica grains and these are separated using a hydrocyclone. The underflow fraction is further treated by flotation to remove iron oxide minerals, then filtered, dried and processed by high intensity magnetic separators.

Tailings from slimes, flotation and magnetic separation may represent about 13% of sand feed, or 24% of equivalent ore feed. The flint sand thus obtained can be marketed as is, or can be ground further in a pebble mill to produce a higher quality silica flour.

3.5 Fine Grinding

The 75 and 45 µm silex grade silica flours are produced in two pebble mills in closed circuit with a variable speed Gyrotor classifier.

Figure V illustrates a typical process flow diagram and Table 3 gives a typical equipment list, including motor electrical data and estimated power demand values.

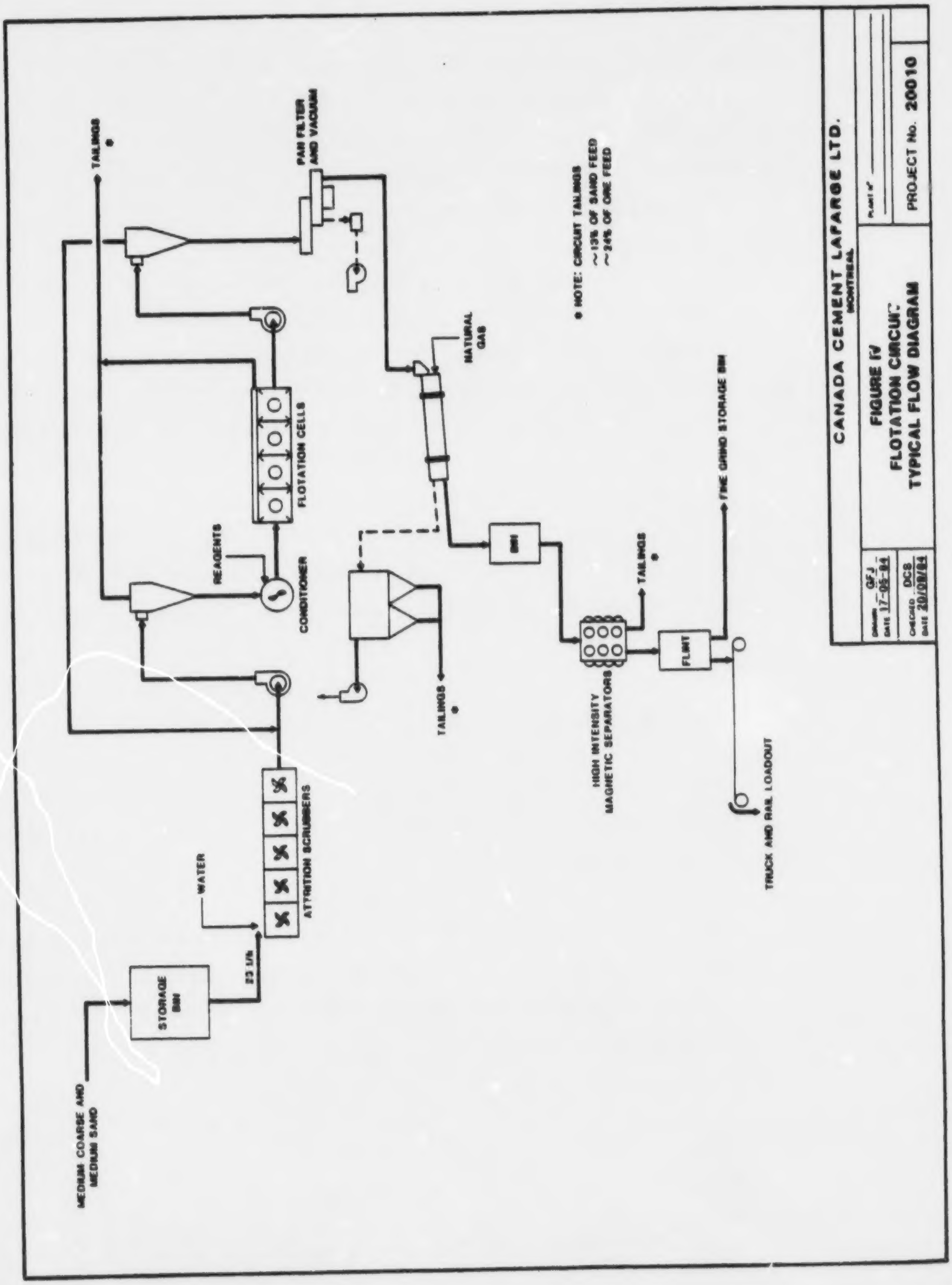
MEDIUM COARSE AND MEDIUM SAND
STORAGE BIN
23 t/h
WATER
ATTRITION SCRUBBERS
REAGENTS
CONDITIONER
FLOTATION CELLS
TAILINGS *
PAN FILTER AND VACUUM
NATURAL GAS
TAILINGS *
HIGH INTENSITY MAGNETIC SEPARATORS
TAILINGS *
FLINT
FINE GRIND STORAGE BIN
TRUCK AND RAIL LOADOUT
* NOTE: CIRCUIT TAILINGS
~13% OF SAND FEED
~24% OF ORE FEED

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FIGURE IV
FLOTATION CIRCUIT
TYPICAL FLOW DIAGRAM

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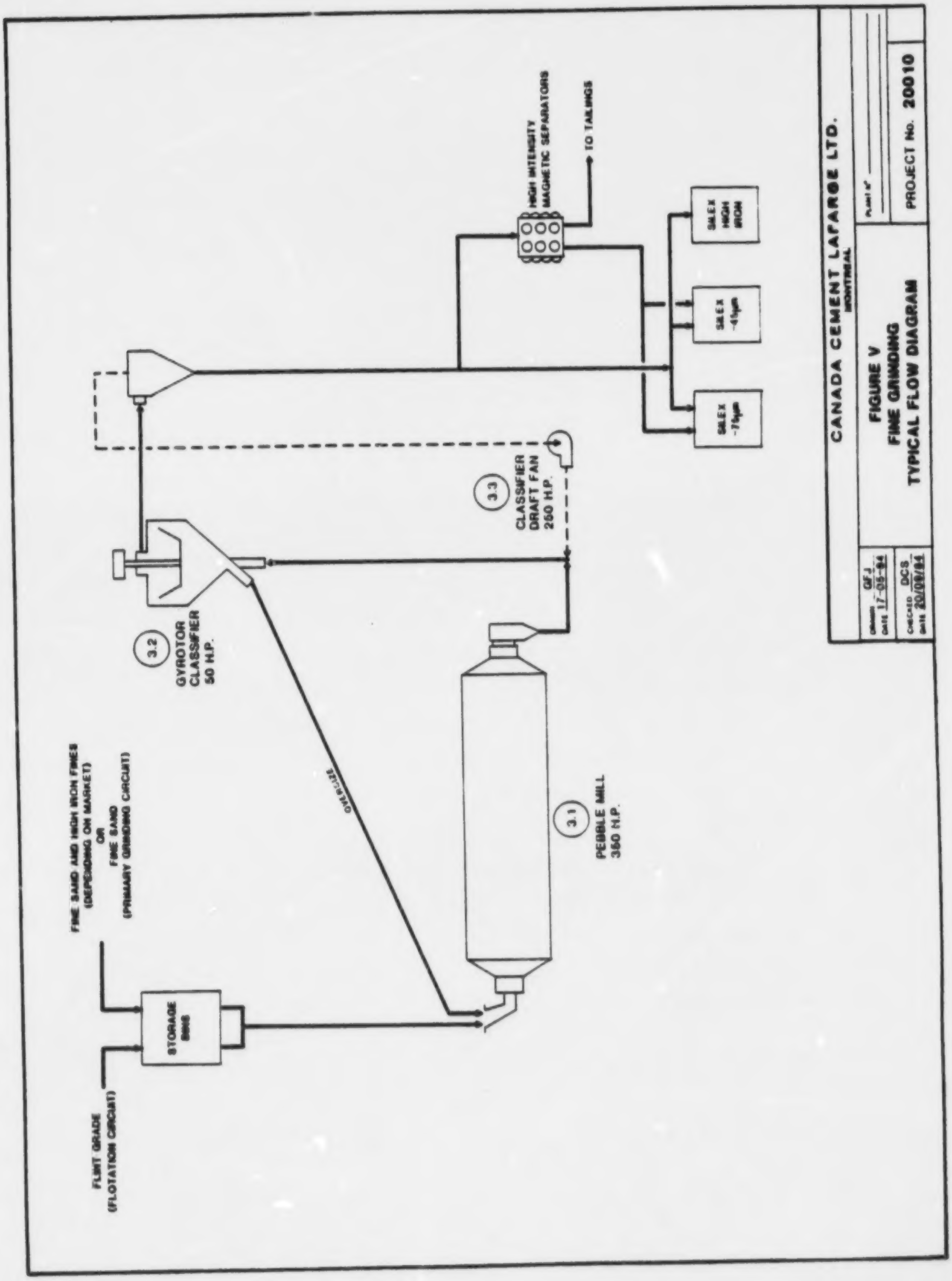
PROJECT No. 20010


FLINT GRADE
(FLOTATION CIRCUIT)
STORAGE
BINS
FINE SAND AND HIGH IRON FINES
(DEPENDING ON MARKET)
OR
FINE SAND
(PRIMARY GRINDING CIRCUIT)
OVERSIZE
3.1
PEBBLE MILL
350 H.P.
3.2
GYROTOR
CLASSIFIER
50 H.P.
3.3
CLASSIFIER
DRAFT FAN
250 H.P.
HIGH INTENSITY
MAGNETIC SEPARATORS
TO TAILINGS
SILEX
HIGH
IRON
SILEX
-45μm
SILEX
-75μm
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PLANT N°
PROJECT No. 20010
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DATE 17-05-84
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FIGURE V
FINE GRINDING
TYPICAL FLOW DIAGRAM

TABLE 3 - Fine Grinding - Typical Equipment List: Electrical Data and Estimated Power Demand

		MOTOR* HP	POWER DEMAND kW
No.	EQUIPMENT		AVG.
3.1	Pebble Mill - 7' x 26' - 4160V	350	200
3.2	Gyrotor Classifier - 500 DC	50	35
3.3	Classifier Draft Fan - 575V	250	170

* All motors 550V unless noted

Fine sand (-106 µm) is the usual feed for the 7' diameter by 26' pebble mills which are driven by 350 HP motors. The mills have 45% of their volume loaded by high density alumina pebbles. The mill discharge is air swept to the classifier in a closed airflow circuit generated by a 250 HP draft fan. Variable speed selector blades (Gyrotor design) allow a fine control of the cut point. The oversize is feed back to the mill, creating a circulating load up to 400%. A cyclone extracts the fines that may be further treated in a high intensity magnetic separator for final iron removal.

Production rates of the pebble mill system vary from 4.5 t/h on the 75 µm silex grade to 2.7 t/h on the 45 µm silex grade.

4. RESULTS AND DISCUSSIONS

The energy consumption data have been calculated on the basis of estimated power demand values and production rates given in the preceding section.

Results are grouped according to circuit operation. Products average specific energy consumption is also reported in a cumulative basis. No particle size distribution data could be obtained and no grindability testing was done, but a typical Bond index value is given.

4.1 Ore Crushing and Drying

4.11 Power Demand Estimates

The crushers average power demand totals 300 kW (see Table 1) representing a loading of about 55-60% of installed power. The estimates have been based on typical average loading for the respective crusher type, ranging from 33% on the jaw crusher to 80% on the gyrasphere crusher. Besides the dryer draft fan, two dust collectors, one for crushing and the other for screening, draw 60 kW together; their power demand has been estimated on 80% motor loading. The dryer drive and draft fan motor loads have been estimated at 50% and 75%, respectively.

4.12 Specific Energy Consumption

Table 4 gives the specific energy consumption for crushing and drying and shows that comminution represents 58% of the total. Although this proportion is typical of crushing circuits, at 2 kWh/t, the consumption for silica ore crushing is higher than for other minerals (typically around 1 kWh/t).

TABLE 4 - Silica Ore Crushing and Drying Specific Power Consumption

	kWh/tonne	%
Comminution	2	50
Auxiliaries	2	50
Total	4	100

A complete distribution of consumption is given in Table 5. Drying accounts for a large portion of total consumption and equals 1 kWh/t when expressed in specific terms. Dust collection does not represent a consumption item as important as seen for other minerals.

TABLE 5 - Silica Ore Crushing and Drying Distribution of Consumption

	%
Crushing	58
Ore Feeding	2
Screening	2
Drying	26
Dust Collection	12

4.2 Primary Grinding and Classification

4.21 Power Demand Estimates

Grinding is conducted by a rod mill drawing an average demand of 300 kW, equal to 80% of installed capacity. Classification is a major source of energy consumption, particularly on account of the whizzer classifier draft fan which is highly loaded at more than 90% of nominal power. Power demand for dust collection has been estimated on 80% motor loading.

4.22 Specific Energy Consumption

Table 6 gives the circuit specific energy consumption. Comminution has a smaller share of total consumption because of the increased importance taken by classification and dust collection (Table 7).

TABLE 6 - Primary Grinding and Classification Specific Power Consumption

	kWh/tonne	%
Comminution	8.6	46
Auxiliaries	10.0	54
Total	18.6	100

TABLE 7 - Primary Grinding and Classification Distribution of Consumption

	%
Grinding	46
Classification	35
Dust Collection	19

4.3 Fine Grinding

4.31 Power Demand Estimates

The fine grinding circuit is a simpler one involving only three motors, two being large power consumers. The pebble mill runs on average at just over 75% of nominal power. The classifier draft fan is again highly loaded at about 90% of nominal power. The gyrotor classifier is running at almost full power.

4.32 Grindability

A Bond Work Index value of 26 kWh/ton is believed to be representative for a typical quartzite silica ore.

4.33 Specific Energy Consumption

Energy consumed in the fine grinding circuits is distributed equally between the pebble mills and their classifiers. The capacity of the circuit is limited by the size of the mill fan and classifier and their motors. Finer products result in higher circulating loads, lower feed rates and proportionately higher unit energy consumption. This is shown on Table 8.

TABLE 8 - Silex Grade Fine Grinding Specific Power Consumption

Product	Grinding (kWh/tonne)	Auxiliaries (kWh/tonne)	Total (kWh/ tonne)	Comminution Consumption (%)
Silex 200	44	46	90	49
Silex 325	74	76	150	49

4.4 Products Specific Energy Consumption

An average specific energy consumption for the various silica products is presented in Table 9. These values are cumulative and take into account the product yield in the various circuits. For instance, the sand grades include the specific consumption for primary grinding and classification plus that for ore crushing and drying, corrected for the high iron fines lost to tailings. The flint grade specific consumption is calculated to take into account tailings in the flotation and the primary grinding and classification circuits. For silex grades, a 50:50 sand and flint feed was selected to calculate the cumulative specific consumption.

TABLE 9 - Silica Products Cumulative Consumption
Average Specific Power Consumption

Product	Comminution (kWh/tonne)	Auxiliaries (kWh/tonne)	Total (kWh/ tonne)	Comminution Consumption (%)
Sand Grades	11	12	23	48
Flint Grade	13	13	26	50
Silex 200	56	59	115	49
Silex 325	86	89	175	49

For all products, the specific energy consumption values determined for comminution are high and can be explained by the high Work Index value of quartzite. In this regard, it is noteworthy that the silex 200 comminution consumption (56 kWh/t) is more than double the Bond Work Index value. This fact may represent a subject worthy of further study: one may wonder if the energy consumption of an industrial mill system is greater than that of the Bond test mill on account of the classification inefficiency, the high circulating load, the material transport properties through the mill or a combination of the preceding factors.

In examining the total specific consumption, energy is seen to be shared equally between comminution and auxiliaries for all types of products. This may be peculiar to silica processing. Compared to other minerals previously investigated, the specific energy consumptions are high and put silica recovered from quartzite deposits in the higher energy consumers.

5. CONCLUSIONS AND RECOMMENDATIONS

The energy consumption for comminution of quartzite ores for the production of silica grade is high relative to other minerals studied. The high consumption is related to the hardness of the ore as measured by the Bond Work Index and the energy consumed by auxiliary equipment for dust control and air classification.

Product specific energy consumptions range from 23 and 26 kWh/tonne for sand grade and flint grade, respectively, to 115 and 175 kWh/tonne for Silex 200 and Silex 325, respectively. In each case, the energy consumption for auxiliaries accounts for half of the total consumption.

The high energy consumption on a product basis results mainly from high circuit energy consumption and, partly, from beneficiation inducing the wastage of ground material when making sand and flint grades.

The energy cost for comminution and associated operations is believed to account for about 40% of electrical costs which, in turn, represent about 12% of total operating costs.

The savings potential would appear to lie mainly in the area of auxiliaries which impact so greatly the total consumption for comminution and associated operations. This remark is referring specifically to the use of external draft-type classifiers in the removal of high iron fines in the sand circuit and in the pebble mill circuits for silex grade production.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Silica occurs in abundance on the earth's surface in a variety of forms. It is an industrial mineral with which Canada is particularly well endowed. It occurs chiefly as quartz, but is found in many forms including sand, sandstone, quartzite and vein quartz.[1]

The term "silica" refers to silicon dioxide (SiO_2) in all its crystalline, amorphous and hydrated or hydroxylated forms.

Silica deposits are mostly of detrital origin and are composed essentially of the mineral quartz, which was originally derived through the weathering of a quartz-bearing igneous rock, such as granite. Hence, the deposits are often composed of the constituent minerals of granite: quartz, feldspar, mica and hornblende, with possible accessories such as zircon, tourmaline, garnet, magnetite and pyrite. The result is an impure, low silica sand. Workable deposits of silica are of four types: unconsolidated silica sand, sandstone, quartzite, and pegmatitic quartz.[2]

Canadian sand deposits are often of glacial origin. Sands derived from glacial debris usually consist of extremely heterogenous material. For this reason, high purity silica deposits are scarce. Such glacial formed deposits can furnish large tonnages of sand suitable for silica flux, foundry sand, and other uses not requiring a high degree of purity.[2]

Sandstones are the most widely used sources of silica sand. They consist of aggregates of sand grains bonded by a mineral cement, usually silica or calcareous material. When the quartz grains of a sandstone are recrystallized by metamorphism, the rock becomes a quartzite and loses the granular texture of the original sandstone. During the mining of many granite pegmatites for feldspar, considerable tonnages of quartz must also be mined which may be sold as lump silica for use as flux.[2]

Silica occurs as the mineral quartz in a variety of rocks and unconsolidated sediments. Although it is one of the most abundant minerals, making up an estimated 12 per cent of the earth's crust, commercial sources of silica are presently restricted to uncommonly pure deposits. Further, because of its low unit value, an economically viable deposit should normally be mineable by low cost, open pit methods, and, ideally, be located close to consuming areas in order to minimize transportation costs.[3] Deposits of lower purity are being investigated as possible sources of high grade sand, if beneficiation costs can be minimized.[4]

The principal uses for silica are: as the chief constituent in glass, as metallurgical flux, in the manufacture of silicon carbide, as silicon ore for ferrosilicon, as foundry sand for metal castings, in sand blasting, and as filler material in tile, asbestos cement pipe, concrete and bricks.[3]

Mining can be done by underground or open pit methods, depending on the location of the deposit and cost. Loading is done by shovel and then the material is hauled by truck or rail to the plant. Further processing steps depend on how consolidated and how pure is the stone. In general, primary crushing is done by jaw, gyratory, cone, or roll crushers. Where the material is of poor coherence, an impact crusher of the hammer mill type will reduce much of the rock to a sand product in one stage. Otherwise, final reduction to grain size, is accomplished with one of several types of crushers/grinders such as: ring-roll, roller, ball, or rod mills (to 600 μm).[2]

Although normally performed dry, reduction of sandstone may also be achieved by wet processing. When wet milling is employed, the cost of drying, particularly in the fine sizes, will be appreciable.[2]

Where fine grinding is necessary to produce a sand or flour product, dust becomes a serious problem. Air classification is employed in a dry milling circuit. In between steps, the desired size product is removed by screening following each pass.[2]

Washing and scrubbing may be done at various stages to remove fines and some impurities, surface coatings, etc. Where silica sand is beneficiated by washing, hydraulic classification is frequently used.[2]

Other steps to remove impurities include: flotation, magnetic or electrostatic separation, and acid leaching.[2,4]

The Canadian Industry

Silica deposits have been developed in virtually every province. Table 1 gives a breakdown of production by province and by use for recent years. While, historically, Ontario produces the highest tonnage of silica sand, Quebec produces more of the higher-value, high-purity sand, thus reporting a greater value of production in spite of lower volumes. Exceptionally, in 1982, the volume in Quebec was larger than that in Ontario, due to a drastic reduction in that province caused by the recessionary slowdown, particularly in the use as smelter flux in the nickel ore processing industry.

TABLE 1 - Canada, Silica Production 1981 and 1982[3]

PRODUCTION, QUARTZ AND SILICA SAND	1981		1982P	
	(000t)	($000)	(000t)	($000)
By province				
Quebec	694	12,950	706	13,781
Ontario	901	10,969	482	8,292
Alberta	..	3,173	..	3,088
Manitoba	198	2,284	164	2,688
Nova Scotia	..	2,334	..	1,401
New Brunswick	..	1,000	..	1,400
Saskatchewan	142	1,169	97	1,049
Newfoundland	..	768	..	1,632
British Columbia	..	46	..	36
	2 238	34,693	1 797	33,367
By use				
Glass and fiberglass	489	12,542	..	..
Flux	837	4,054	..	..
Ferrosilicon	339	3,193	..	..
Other uses[1]	573	14,904	..	..
	2 238	34,693	1 797	33,367

Approximately 40% of silica produced in Canada is low-value lump and sand consumed as metallurgical flux. High-quality silica sand suitable for the manufacture of glass is produced by two companies in Canada. Indusmin Ltd., the largest, operates beneficiation plants in southern Ontario and Quebec. Steel Brothers of Canada Ltd. quarries high-grade silica sandstone on Black Island in lake Winnipeg and processes the material at Selkirk, Manitoba (see Table 4 for a list of major Canadian producers).[3]

Canada imports high-grade silica sand for use in glass manufacturing, and sand suitable for foundry castings, silex and crystallized quartz and silica brick.[3] These imports concern mainly silica sand and come essentially from the United States. Table 2 gives the evolution of silica production, trade and consumption during the last decade. The data show the irregularity of consumption during this period having a direct impact on the volume of production while the level of imports generally remained stable. Imports account for about 30% of consumption, exports concern quartzite and are small relative to imports. The data for 1982 show the large decrease in both production and imports reflecting the downturn of the Canadian economy.

TABLE 2 - Canada, Silica Production and Trade,
1970, 1975, 1978-82[3]
(tonnes)

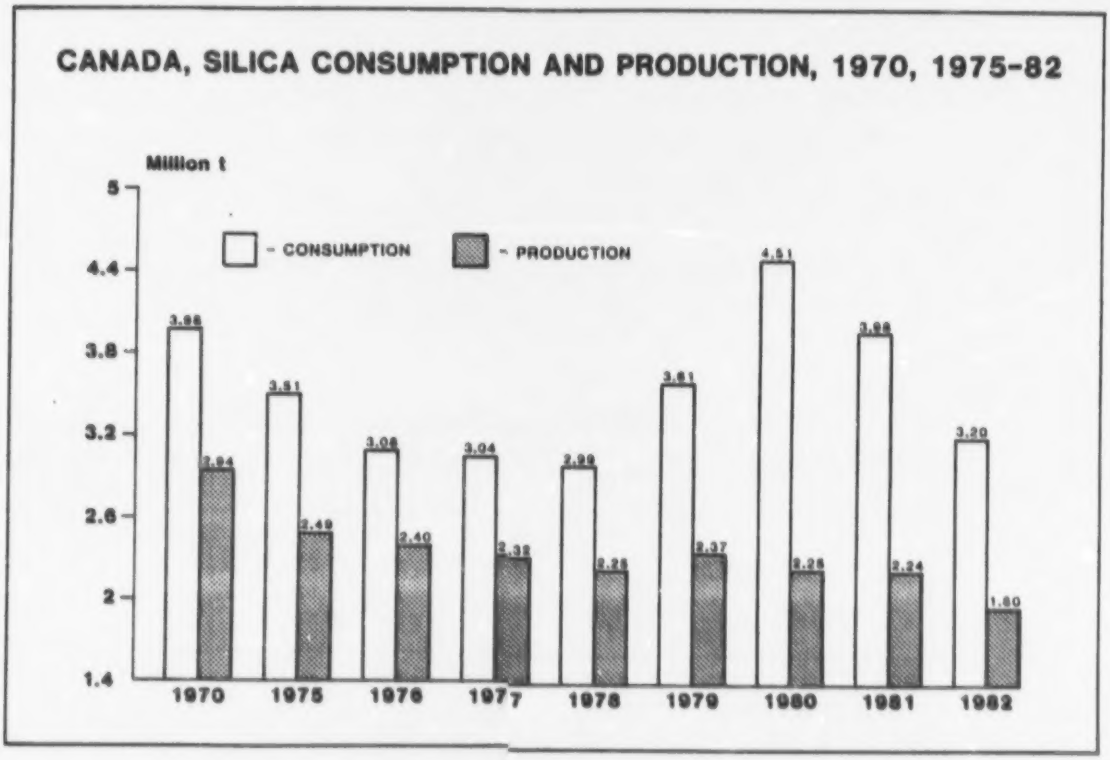
PRODUCTION		IMPORTS			EXPORTS	CONSUMPTION
Year	Quartz & Silica Sand	Silica Sand	Silex or Chrystallized Quartz	Fire-brick & Similar Shapes	Quartzite	Quartz & Silica Sand
1970	2 937 498	1 176 199	186	2 020	58 917	3 979 305
1975	2 491 715	1 044 160	1 550	18 818	39 977	3 510 818
1978	2 245 136	1 242 444	1 955	6 948	67 775	2 987 736
1979	2 368 497	1 651 890	1 259	4 896	60 823	3 611 815r
1980	2 252 000	1 200 237	281	4 775	63 166	4 512 637
1981	2 238 000	1 142 880	251	13 762	119 347	3 983 751
1982P	1 797 000	788 768	241	2 984	65 333	..

P Preliminary; .. Not available; r Revised.

The trend of silica consumption and production during the last decade has been on the decrease; this fact is best illustrated by Figure I.

FIGURE I - Canada, Silica Consumption and Production Volumes 1970, 1975-82[3]

(in million tonnes)



Source: Canadian Minerals Yearbook 1982, EMR Canada.

Although the downward trend on consumption was reversed from 1979 and onwards, the production has not followed the same way. In 1982, the production declined substantially (see Table 2).

A typical breakdown of consumption by major industries can be seen in Table 3.

TABLE 3 - Canada, Estimated Consumption of Silica by Industries, 1980 and 1981[3]

	1980	1981
Foundry sand	1 366 152[r]	1 085 481
Glass manufacture (including glass fibre)	968 019	951 442
Smelter flux[1]	1 192 868[r]	837 203
Refractory brick mixes, cements	512 416	359 163
Artificial abrasives	130 461	125 706
Metallurgical	67 812	143 447
Chemicals	38 603	39 430
Gypsum products	8 850	2 314
Concrete products	63 254	211 608
Fertilizer, stock poultry feed	4 172	3 982
Other[2]	160 030	223 975
Total	4 512 637[r]	3 983 751

[1] Producers' shipments of quartz and silica for flux purposes.
[2] Includes asbestos products, ceramic products, frits and enamels, paper & paper products, roofing & other minor uses.
[r] Revised.

Three large consuming industries can be identified: they are the ferrous metal industry using foundry sand, the glass manufacturing industry and the non-ferrous metal processing industry using smelter flux.

Silica producers in Canada are listed in Table 4 with name of companies and quarry locations.

TABLE 4 - Canadian Producers of Silica, 1983

PROVINCE - COMPANY	LOCATION
Newfoundland	
1. Erco Industries Ltd. (Dunville Mining Company)	Villa Marie
Nova Scotia	
2. Nova Scotia Sand & Gravel Ltd.	Shubenacadie
New Brunswick	
3. Chaleur Silica Ltd.	Bass River
Quebec	
4. Baskatong Quartz, Inc.	Charlevoix
5. Indusmin Ltd.	St-Donat
(Quebec Silica Division)	St-Canut
6. Sable de Silice Crêmazie Inc.	Ormstown
7. Armand Sicotte & Sons Ltd.	Ste-Clotilde
Ontario	
8. Indusmin Ltd. (Ontario Silica Division)	Killarney
9. B-Mac Silicon Aggregates Ltd.	Bracebridge
Manitoba	
10. Steel Brothers Canada Ltd.	Black Island
Alberta	
11. Sil Silica Ltd.	Bruderheim

Source: Energy, Mines and Resources Canada

Market Outlook

There are indications that the Canadian Silica industry is awaiting the end of the current recessionary conditions to undergo a period of significant growth. Because metallurgical flux consumes almost half of the silica produced, a recovery in the base-metal industries would be necessary to boost silica tonnages significantly. Amounts of silica consumed in the manufacture of glass and glass fibre, as well as foundry sand can be expected to increase as the markets for these products improve.[3]

Top-quality, low-cost sand is readily available from suppliers in the U.S.A., therefore discouraging large-scale development of available Canadian silica sand sources. The U.S. deposits are very pure, requiring only simple, low-cost mining and processing. Combined with low freight rates, it is possible for U.S. suppliers to sell silica in Canada at a low price. Canadian producers are at a disadvantage because the nature of the deposits requires more intensive and higher cost processing, and transportation costs to markets are at a much higher rate per tonne per kilometer. However, some producers are competing effectively by increasing their tonnage of premium grade silica sand, thus increasing the quantity of high-purity domestic sand available to consumers. A continuation of this trend will significantly decrease imports of this commodity.[5]

In the long term, the fields of fibre optics, solar grade silicon and quartz culture are likely to become important consumers of silica. Significant improvements in mineral processing technology would be required for any of the current Canadian operations to achieve these stringent raw material specifications.[3,5]

Silica occurs in many forms, from unconsolidated sand and quartz to opal (an amorphous form). Deposits of industrial interest vary in purity, sometimes as much as 98% SiO_2, often much less. Common impurities include alumina, iron, calcite, magnesia, mica, and clay. The chemical composition of samples of Ontario silica are shown in Table 5.

TABLE 5 - Chemical Composition of Silica Samples[2]

COMPONENT	SAMPLE %		
	1	2	3
SiO_2	98.19	96.98	99.40
Al_2O_3	0.94	1.76	0.30
F_2O_3	0.36	0.75	0.13
FeO	-	-	0.13
MgO	0.06	0.05	-
CaO	0.03	0.03	-
TiO_2	0.05	0.09	-
Na_2O	0.07	0.04	-
K_2O	0.50	0.50	-

NOTE:
1. Killarney, Ont. - quartzite
2. Crosby, Ont. - quartzite
3. Kingston, Ont. - Potsdam Sandstone

Physical and chemical properties can often be modified to meet specific user specifications. Qualities of interest include: particle size, particle shape (determines abrasiveness), and the level of certain impurties. Silica melts at 1728°C and has the ability to sustain loads even when temperatures approach the melting point, making it an extremely useful refractory material.

Some physical properties are shown in Table 6.

TABLE 6 - Properties of SiO_2 (Quartz)[6]

Specific Gravity	2.65
Melting Point (°C)	1610
Solubility	Insoluble in H_2O, soluble in HF, slightly soluble in alkali
Refractive Index	1.55
Hardness (mohs scale)	7

Uses of silica include: the manufacture of ferrosilicon, silicon carbide, glass, sodium silicate and enamels; as foundry flux in acid process, as refractory brick, and industrial fillers.

In examining a deposit with a view to commercial utilization, specifications may require that the following features be investigated:[2]

1. Mineralogy; what percentage of silica; what accessory minerals.
2. Chemical purity, including analysis of silica, alumina, iron, lime, magnesia and alkalis.
3. Grain size: sizing and sorting of the grains checked by sieve analyses.
4. Roundness or angularity of the grains.
5. Toughness of the grains.
6. Cleanliness and percentage of fines present.

Specifications set by consumers depend on intended use. Table 7 shows criteria by use.

TABLE 7 - QUALITY CRITERIA FOR SILICA, BY USE[1]

FORM	USE	SPECIFICATIONS		
		Grain Size	% Impurities	Other
Lump Silica	Flux	8 - 25 mm	High silica content, iron and alumina not serious in small quantities	Should not decrepitate
	Silicon Alloys	25 - 150 mm	$SiO_2 > 98\%$; Fe_2O_3 & $Al_2O_3 < 1\%$ or $< 1.5\%$ combined. Lime and magnesia $< 0.2\%$, no phosphorous arsenic	
	Silica Brick	- 2.36 mm	$SiO_2 > 97\%$; Fe_2O_3 & $Al_2O_3 < 1\%$ or $< 1.5\%$ combined; low lime & magnesia	
	Aggregate Abrasive	Depends on use		Used in concrete and as grinding media
Silica Sand	Glass	100 - 600 µm	99.6% SiO_2; 0.03% Fe_2O_3; 0.15% Al_2O_3, low lime, magnesia & moisture	Uniformity & grain size important Angular grains preferred
	Silicon Carbide	+ 150 µm (the bulk +500 µm)	$SiO_2 > 99\%$; Fe_2O_3 & $Al_2O_3 < 0.1\%$ each. No lime, magnesia & phosphorous	
	Hydraulic Fracturing	500 - 850 µm	- No acid consuming constituents - High SiO_2	- Well rounded grains - Clean and dry - High compressive strength
	Foundry	70 - 850 µm	SiO_2 high; low aluminum, iron, sodium & potassium oxides	Well rounded grains in closely sized ranges
	Sodium Silicate & Other Chemicals	150 - 850 µm	$SiO_2 > 99\%$; $Al_2O_3 < 0.25\%$; lime and magnesia combined $< 0.05\%$; $Fe_2O < 0.03\%$	
	Other Uses	Coarsely ground Closely sized		Used as grit in sand blasting, sandpaper, water filtering media, cement manufacturing
Silica Flour	-Enamel frits -Filler in paints, rubber -Abrasive in Soaps and Cleansers	Fine Powder	$SiO_2 > 97.5\%$; $Al_2O_3 < 0.5\%$, $Fe_2O_3 < 0.2\%$	

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REFERENCES

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PROCÉDÉ *Planilex* PROCESS
MONTREAL, QUEBEC

TALC

THE TALC INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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TABLE OF CONTENTS

Page No.

1. INTRODUCTION 1

2. COMPANY DESCRIPTION 2 - 3

2.1 Products 2
2.2 Raw Material 2

3. PROCESS DESCRIPTION 4 - 12

3.1 General 4
3.2 Crushing and Screening 4
3.3 Raymond Mill 7
3.4 Flotation 8
3.5 Pulverizer Circuit 11

4. RESULTS AND DISCUSSION 13 - 24

4.1 Talc Ore Crushing and Grinding 13

4.11 Electrical Measurements 13
4.12 Flowrates 14
4.13 Size Distribution 16
4.14 Grindability 18
4.15 Specific Energy Consumption 19

4.2 Flotation and Pulverization 20

4.21 Electrical Measurements 20
4.22 Flowrates 20
4.23 Size Distribution 21
4.24 Specific Energy Consumption 22
4.25 Comminution Power Consumption by Product 22
4.26 Chemical Composition and Brightness 24

5. CONCLUSIONS AND RECOMMENDATIONS 25 - 26

APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Bakertalc Inc.

Plant Location:

Highwater, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the talc industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 Products

Bakertalc Inc., a Canadian company formed in the late 1930's, operates a mine at South Bolton and a milling plant at Highwater with a head office in Montreal.

The plant has a capacity of about 10,000 tonnes per annum. Three major grades of talc are produced: ground products A1 and A3, and floated and pulverized product #903. Another ground product A2 is produced in small quantities.

Product A1 is 95% passing a 45 µm sieve while product A3 is 99.8% passing 45 µm. The talc content of these products is 65-70%.

Product #903, having passed through the flotation process, is 98% talc with an average particle size of about 1 µm. The loss on ignition (L.O.I.) is 5-6% while that of pure talc is 4.2%.

Marketing and distribution of Bakertalc products, shipped in 25 kg bags, are handled by St. Lawrence Chemicals of Montreal. The main geographical market areas are Quebec and Southern Ontario.

2.2 Raw Material

The talc ore is obtained from an underground mine located about 15 kilometers from the plant. The deposit is a mixture of hard and soft talc and soapstone. The mining operation is carried out at approximately 200 m below the surface, using the blast hole stoping method into a 75 m glory hole. Selective mining controls the composition of the rock. The ore is then moved to a 2.25 m^3 bucket in an inclined shaft to the surface. The mined ore is stored in loading bins and trucked to the mill.

The talc ore varies in size distribution, chemical analysis, and moisture. The size distribution of the ore was observed to be a maximum size of about 25 cm slabs with 40% of the material passing 5 cm. Due to moisture content, some fine material in the ore adheres to the larger pieces and passes over the screen to the crusher.

The plant operators do not attempt to control the chemical composition of the ore as produced by selective mining but accept the material for processing as received.

3. PROCESS DESCRIPTION

3.1 General

The production line at the Bakertalc plant consists of a mixture of older, less sophisticated equipment as well as machines of very recent design involving some of the most modern processing techniques. The process can be subdivided into four stages; primary-secondary crushing and drying, the Raymond mill grinding circuit and associated equipment, the flotation process, and the Bauer Hurricane pulverizer circuit. The flotation and Bauer Hurricane circuits are closely linked since all the flotation product is processed through the pulverizers. Figure I shows a schematic arrangement of the Bakertalc process flow. Since all products are generally bagged as they are produced, the bagging department can be considered as part of the process department.

3.2 Crushing and Screening

Ore is held in a bin leading to a vibrating screen-feeder (Figure II) equipped with a single deck of 65 cm x 65 cm and 5 cm openings. It is driven by a 5 HP motor and the feed rate is controlled manually by on-off action. The screen oversize discharges to a jaw crusher of 60 cm x 30 cm opening and a discharge opening of about 5 cm. The crusher drive is 50 HP.

The vibrating screen undersize drops to a belt and is fed to a rotating dryer fueled by No. 2 furnace oil. The dryer is of approximately 1.25 m diameter by 4.5 m in length and is fitted with lifters to pick up the material and drop it through the airstream. Draft through the dryer is supplied by a 10 HP induced draft fan venting directly to atmosphere. Material passes through the dryer

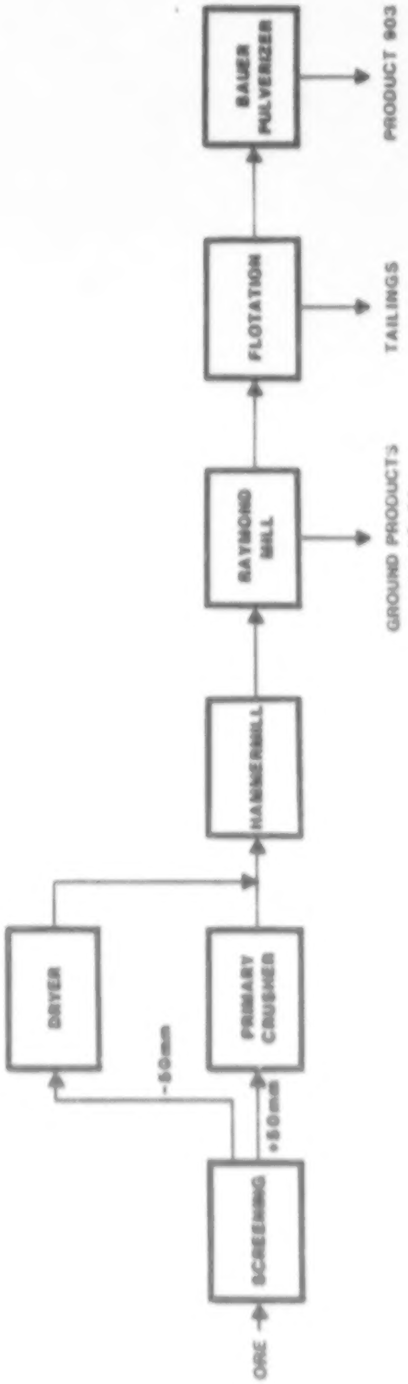
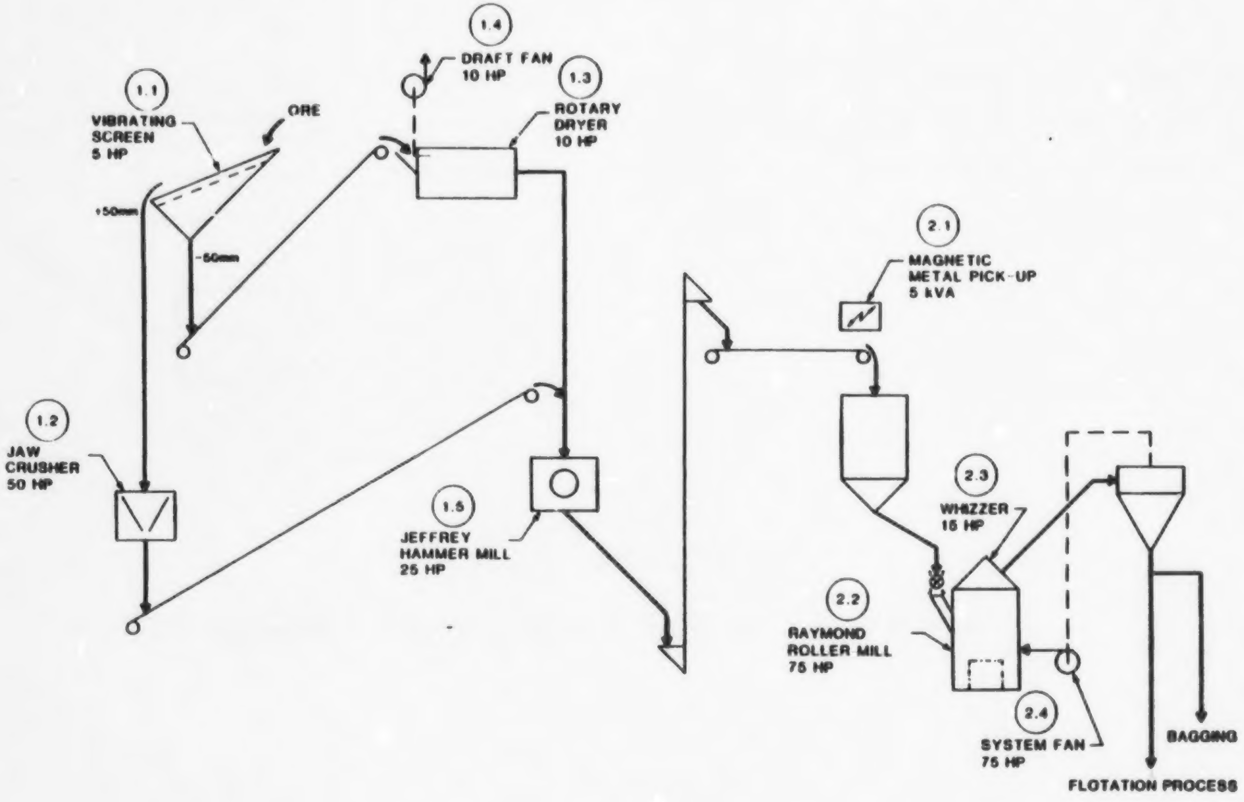

ORE
SCREENING
+50mm
-50mm
DRYER
PRIMARY CRUSHER
HAMMERMILL
RAYMOND MILL
GROUND PRODUCTS A1, A2, A3
FLOTATION
TAILINGS
BAUER PULVERIZER
PRODUCT 903

Figure I - TALC PROCESS FLOW SHEET

BAKERTALC, INCORPORATED
Highwater, Quebec

3. PROCESS DESCRIPTION (cont'd)


1.1
VIBRATING SCREEN
5 HP
ORE
+50mm
-50mm
1.2
JAW CRUSHER
50 HP
1.4
DRAFT FAN
10 HP
1.3
ROTARY DRYER
10 HP
1.5
JEFFREY HAMMER MILL
25 HP
2.1
MAGNETIC METAL PICK-UP
5 kVA
2.2
RAYMOND ROLLER MILL
75 HP
2.3
WHIZZER
15 HP
2.4
SYSTEM FAN
75 HP
BAGGING
FLOTATION PROCESS

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 04/08/83
CHECKED DCS
DATE 20/09/84

FIGURE II
CRUSHING & GRINDING
FLOW DIAGRAM

PLANT BAKERTALC - HIGHWATER, P.Q.

PROJECT No. 20010

counter current to hot combustion gases. The fuel rate is adjusted by a fuel valve and the overall fuel consumption is measured monthly by inventory checks. The drive is equipped with a 10 HP motor.

The dried material mixes with material from the jaw crusher and feeds directly to a 25 HP Jeffrey Mini-Mill.

The -2 cm material goes by elevator and belt conveyor to storage bins. The head pulley of the belt serves as a 5 kVA electro-magnet with adjustable current control to remove scrap metal. Crushed ore is reclaimed from the storage bins by elevator. A second belt conveyor delivers feed directly to the roller mill feed bin.

While the hammermill is the bottleneck in the crusher department, the system has sufficient capacity to operate only a few hours a day to supply the rest of the plant with feed.

3.3 Raymond Mill

The roller mill, in a sense, represents the core of the process, since all products made at Bakertalc pass through this mill at some stage in their processing. The mill is a Raymond "High-Side" model 5458 powered by a 75 HP motor. Grinding action takes place between rollers and a grinding table.

The Raymond mill has an internal classifier that recirculates particles not meeting fineness requirements to the grinding zone. The classifier, or whizzer, consists of a set of revolving blades, the speed of which determines the size of the particles allowed to pass through. The whizzer is powered by a 15 HP drive which is independent of the mill drive. The motor is coupled to the whizzer through an infinitely variable speed ratio transmission.

Ground material is circulated in the mill and subsequently removed by an upward air sweep through the mill. This air sweep is provided by a 75 HP system fan located with its outlet near the bottom of the mill. Air is forced into the bottom of the mill and upward through a duct carrying with it particles of finished product. The air passes through a cyclone where the entrained material is removed and then returns to the inlet of the system fan for recirculation to the mill. The air sweep is essentially closed circuit. The material removed from the airstream by the cyclone then passes to the bagging bin or flotation feed bin depending on the product being made.

The Raymond mill is fed by gravity through a rotary feeder. The feed rate and, consequently, the load in the mill, is controlled by on-off action of the rotary feeder. The controlled variable is the differential pressure across the mill, which is proportional to mill load. Air taps at the bottom and top of the mill provide differential pressure measurements to a switch operating at a setpoint. Despite the non-continuous nature of the control, the mill loading is kept relatively constant.

3.4 Flotation

The flotation circuit separates the talc in the ore from the impurities. A frothing agent is added to a mixture of ground talc ore and water. Particles of talc adhere to froth bubbles in the liquid and float to the surface where the froth and talc are skimmed off.

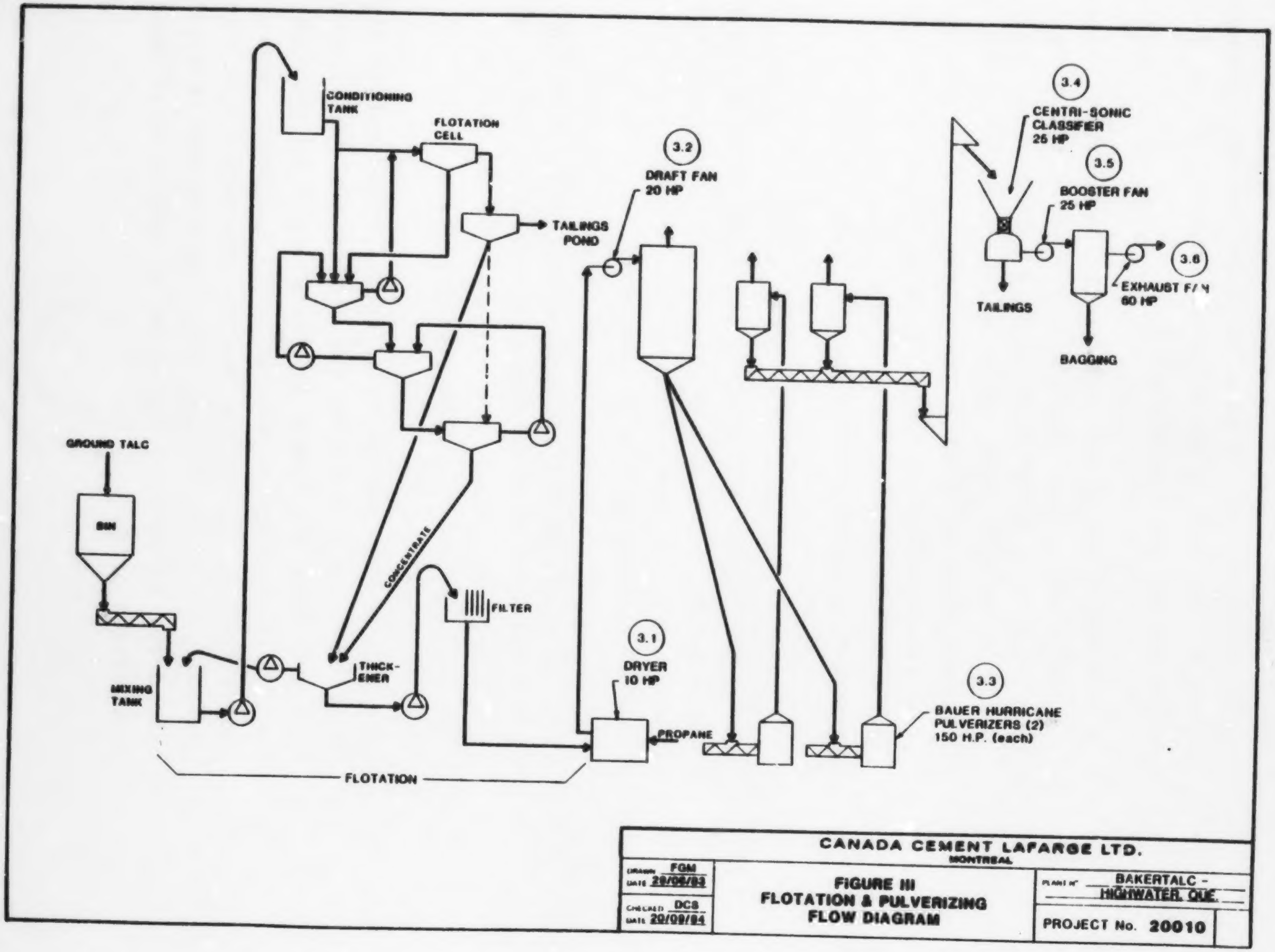
The flotation circuit (Figure III) consists of a mixing tank, conditioning tank, five float cells, thickener and filter. The five float cells are made up of two roughers, two cleaners and a scavenger.

At the Bakertalc plant, the flotation process begins with the talc being fed into the mixing tank by screw conveyor. The tank is kept filled with talc-water slurry, is equipped with a high speed stirrer and provided with a constant flow of water. The slurry is then pumped to the conditioner, another large tank equipped with a stirrer where further mixing takes place and a small quantity of frothing agent is metered in by a pump.

The slurry then passes to the roughers. The concentrate flows to rougher #2, then to the first and second cleaner in sequence. The second cleaner provides concentrate for the thickener. The tailings flow through the circuit is counter current to the floated product.

The thickener densifies the slurry and feeds the filter where moisture content is further reduced. Water from the thickener and filter are returned to the mixing tank at the beginning of the flotation process.

The filter cake passes to a propane fired rotary dryer and flows counter-current to the gas stream. The material is removed from the dryer by entrainment in the gas stream and goes through a fan to a bin-baghouse where it is collected and stored as feed to the Bauer Hurricane mill circuit. A clean burning fuel like propane is required by the dryer to prevent darkening of the floated product by combustion products.


CONDITIONING TANK
FLOTATION CELL
TAILINGS POND
GROUND TALC
BIN
MIXING TANK
THICK-ENER
CONCENTRATE
FILTER
FLOTATION
3.1
DRYER 10 HP
PROPANE
3.2
DRAFT FAN 20 HP
3.3
BAUER HURRICANE PULVERIZERS (2) 150 H.P. (each)
3.4
CENTRI-SONIC CLASSIFIER 25 HP
3.5
BOOSTER FAN 25 HP
3.6
EXHAUST F/ 4 60 HP
TAILINGS
BAGGING

CANADA CEMENT LAFARGE LTD.
MONTREAL

DRAWN FGM
DATE 29/06/83
CHECKED DCS
DATE 20/09/84

FIGURE III
FLOTATION & PULVERIZING
FLOW DIAGRAM

PLANT N° BAKERTALC - HIGHWATER, QUE.

PROJECT No. 20010

3.5 Pulverizer Circuit

The purpose of the Bauer Hurricane mill circuit is to reduce the particle size of the talc from the flotation circuit to the order of 1 μm.

The Bauer Hurricane circuit (Figure III) at Bakertalc is comprised of two 150 HP pulverizer-classifiers operating in parallel, two baghouse collectors, screw conveyor-elevator arrangement to convey material from the baghouses to the single Centri-Sonic classifier, product booster fan at the outlet of the classifier, product baghouse collector and fan. The material for the pulverizer circuit is fed from the holding bin directly to the mills via individual, variable speed screw feeders controlled by mill power demand. The feed enters near the bottom of the mill and passes upward through the grinding zone, made up of blades revolving at high circumferential speed. Grinding action takes place by vortex formation between blades causing inter-particle collisions. This principle is required since the particles are too small to be broken by shock and impact.

The material passes upward through an internal classifier, which consists of a set of blades attached to the same drive shaft as the grinding blades, separating out oversize particles for return to the grinding zone. Air flow is controlled by louvers and is provided by a fan in the top of the pulverizer. Classified material is entrained in the airstream and passes to the individual baghouses. The material then goes to a small bin and is fed at a fixed rate by rotary valve into the top of the classifier. A dispersing rotor disagglomerates feed particles and they pass through the classifier assembly. Classification occurs by the action of the external booster fan which pulls sufficiently fine particles through the rotating assembly. Oversize particles are rejected by centrifugal action and are treated as tailings. "Cut point", the size at which a particle is accepted or rejected, is controlled by speed of the classifier assembly, air flow rate and feed rate. The classifier is driven by a 25 HP motor.

The finished product passes through the 25 HP product booster fan and transport duct to a baghouse that collects the material and feeds it to the bagging machine. The baghouse is exhausted by a 60 HP fan. Table 1 summarizes the equipment in the Bakertalc process.

TABLE 1 - Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Vibrating Screen - 2 in. sq. opening	5	5.5
1.2	Jaw Crusher - 24" x 12"	50	50
1.3	Rotary Dryer (No. 2 Oil)	10	10
1.4	Draft Fan	10	10
1.5	Jeffrey Hammermill (20 x 12)	25	25
2.1	Magnetic Metal Pick-up (5 KVA)	-	10
2.2	Raymond Roller Mill 5458	75	75
2.3	Whizzer	15	15
2.4	System Fan	75	65
3.1	Dryer (Propane)	10	10
3.2	Draft Fan	20	20
3.3	Bauer Hurricane Pulverizer (2) Type 730	150	150
3.4	Centri-Sonic Classifier No. 753	25	25
3.5	Product Booster Fan	25	25
3.6	Dust Collector Fan	60	60

* All Motors are 550 Volts.

4. RESULTS AND DISCUSSION

4.1 Talc Ore Crushing and Grinding

4.11 Electrical Measurements

Measurements in the crushing circuit were made on the crusher and hammermill, rotary dryer drive and induced draft fan. Motors whose consumption tended to vary in response to varying loads were measured with the wattmeter recorder and the consumption characteristics determined directly from the graph. The crusher and hammermill were measured in this manner. For motors with relatively consistent loads, this power consumption was measured by taking amperage measurements and converting to kilowatts.

The Raymond mill circuit involves three motors: the mill motor, the classifier or "whizzer", and the system fan. Since all three components of the system are related to each other with regard to load, each motor was measured with the wattmeter. These measurements were taken while the mill was producing A1 and were repeated for production of flotation feed. While the whizzer and system fan showed fairly constant power consumption rates, some slight fluctuation was observed for the mill motor. This was due to the on-off action of the rotary feeder with the result that the mill load varied slightly around the median point.

Since the Raymond mill system was measured with the wattmeter, all consumptions were reported as maxima, minima and average. Results for the crushing and grinding systems are reported in Table 2.

TABLE 2 - Talc Ore Crushing and Grinding

		MOTOR	POWER OBSERVATIONS - kW		
No.	EQUIPMENT	HP	MAX.	MIN	AVG.
1.1	SCREEN	5			
1.2	CRUSHER	50	11	8	10
1.3	DRYER	10	3	3	3
1.4	I.D. FAN	10	3	3	3
1.5	HAMMERMILL	25	11	4	7
2.1	MAGNET	5 kVA			
2.2	RAYMOND MILL	75			
	PRODUCT A1		29	26	28
	FLOTATION FEED		23	21	22
2.3	WHIZZER	15			
	PRODUCT A1		8	8	8
	FLOTATION FEED		3	2	3
2.4	SYSTEM FAN	75			
	PRODUCT A1		57	56	57
	FLOTATION FEED		52	51	51

4.12 Flowrates

The manner in which the crushing system was operated caused some difficulty in estimating the overall throughput of the system as well as individual stream flowrates. The system was observed in operation and then the decision made to stop the belts while carrying typical loads. A known length of material was removed from each belt. The weight of sample, combined with the measured linear belt speed gave a calculated flowrate. Flowrates for various crushing circuit streams are presented in Table 3.

TABLE 3 - Flowrate Data for Crushing Circuit

Stream	Belt Length Sampled (m)	Sample Weight (kg)	Belt Speed (m/min)	Calculated Flowrate (t/h)
Crusher Product	1.2	37.6	11.4	21.4
Screen Undersize	1.2	28.3	81.9	115.9
Circuit Product	0.94	19.7	18.8	23.6

The flowrate for screen undersize is unrealistically high since, overall, the production rate of the crushing circuit must be roughly the sum of screen undersize and crusher product. This problem is linked to the intermittent nature of the operation. The belt carrying screen undersize has a widely varying load, and, during testing, was stopped at maximum load. While a high flowrate of undersize was indicated, it is estimated that the belt carries this degree of load less than 10% of the time. A more reliable measure of overall production rate was obtained from the product belt, which carried a reasonably steady load.

Although the Raymond mill consists of a grinding zone and a separate classifier unit, it was not possible to treat the mill as closed circuit. The only flowrate which could be estimated for the Raymond mill system was the overall throughput or production rate. This required observation of bagging rate for product A1. Production rate figures for product A3 and flotation feed were obtained from plant records (Table 4).

TABLE 4 - Production Rates for Raymond Mill

PRODUCT	PRODUCTION RATE (t/h)
Flotation Feed	5.0
Product A1	2.3
Product A3	1.0

4.13 Size Distribution

Size distribution determinations were not carried out on screen feed and crusher feed due to the size of sample required to make the test statistically accurate. Therefore, these streams were characterized by observation during actual operation of the crushing system. The results of these observations are as follows:

Stream	Observed Particle Size Distribution
Screen Feed	Maximum Size : 30 cm x 20 cm Average Size : 15 cm - 20 cm Fraction minus 5 cm : 40%
Crusher Feed	Maximum Size : 30 cm x 20 cm Mainly : 15 cm - 20 cm Minimum Size : 5 cm

Samples of screen undersize, crusher product and crushing circuit product were tested for particle size distribution at the Belleville Research Lab of Canada Cement Lafarge Ltd. The results are presented in Table 5.

TABLE 5 - Crushing Circuit Particle Size Distributions

Size	% Passing		
	Crusher Product	Screen Undersize	Circuit Product
63 mm	94.2	100.0	100.0
31.5	29.3	66.5	96.1
25	26.0	61.9	88.8
19	19.7	53.8	75.3
12.5	14.5	44.6	60.7
9.5	11.8	39.1	49.9
4.75	7.9	28.3	32.5
2.36	5.4	20.3	21.8
1.18	3.9	14.2	15.3
600 μm	2.6	8.8	10.7
300	1.9	5.6	7.9
150	1.3	3.5	5.7

The results show that most of the crusher product is between 31.5 mm and 63 mm. Some fine material below 1 mm is also observed in the crusher product. This may result from the crushing itself and from adherence of small particles to the larger ones because of moisture in the ore. These particles are thus carried over the screen to the crusher and are present in crusher product. Analysis of results for screen undersize shows all material smaller than 63 mm with a somewhat larger proportion of -1 mm material as compared to crusher product.

This sample represents the fine fraction of the ore. An important note regarding crushing circuit product is that, while it is intended that all product be minus 19 mm, the results show that, in fact, only 75% of the product meets this requirement. However, it was suggested that some relatively coarse material actually enhances the performance of the Raymond mill.

Particle size distribution testing on the Raymond mill system was done on the flotation feed and products A1 and A3. The results were generated by sedigraph at the Belleville lab and are presented in Table 6. The results show that, with regard to percent passing 45 µm, the finished products from the Raymond mill are essentially meeting specifications. The flotation feed is slightly below the target of 80% passing 45 µm (75% passes according to the sedigraph results).

TABLE 6 - Raymond Mill Particle Size Distribution

Size (µm)	% Passing		
	Flotation Feed	A1	A3
100	98.5	99.0	99.5
70	93.0	97.0	99.0
50	79.5	93.5	99.0
40	70.5	87.0	97.5
30	57.5	74.0	95.0
25	52.0	66.0	91.0
20	43.0	54.5	82.0
15	33.0	42.0	64.0
10	20.0	25.5	35.5
8	15.0	19.5	24.5
6	10.5	13.5	16.5
4	6.5	8.5	10.5
2	2.0	3.0	4.0

4.14 Grindability

On the sample of crushing circuit product, the grindability tests on the Bakertalc ore gave a Bond Work Index and Hardgrove Grindability Index of 8.345 kWh/Ton and 93, respectively. These results typify a material which is relatively easy to grind.

4.15 Specific Energy Consumption

The consumption of electrical energy at Bakertalc expressed as kilowatt-hours per tonne can be calculated for a final product or intermediate material. The specific consumption for the crushing circuit (Table 7) is 0.95 kWh/t. Specific energy consumption for the Raymond mill (Table 8) is significantly higher than for crushing since the fineness of the products is much greater. The percentage of specific energy used for grinding in the Raymond mill remains very nearly the same from product A1 to flotation feed, although the two products are quite different in fineness.

TABLE 7 - Crushing Power Consumption

	kWh/tonne	%
Crushing Only	0.72	76
Auxiliaries	0.23	24
Total	0.95	100

TABLE 8 - Grinding Power Consumption

	kWh/tonne	
	Specific	%
Grinding Only		
Product A1	12.0	30.0
Flotation Feed	4.4	29.1
Auxiliaries		
Product A1	28.0	70.0
Flotation Feed	10.7	70.9
Total Consumption		
Product A1	40.0	100
Flotation Feed	15.1	100

4.2 Flotation and Pulverization

4.21 Electrical Measurements

Electrical energy consumption in the flotation circuit arises mainly from the use of stirrers in the flotation cells and pumps to move the talc-water slurry between the various tanks and cells. Since no comminution takes place, no attempt was made to estimate power consumption.

In the pulverization department, the two hurricane mills and the Centri-Sonic classifier were studied using the wattmeter recorder. The remaining consumers of electrical energy were mainly fans with relatively constant loads. These were measured by amps and the kilowatt demand calculated. The results are presented in Table 9.

TABLE 9 - Purified Talc Pulverizing

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN	AVG.
3.1	DRYER	10	3	3	3
3.2	DRAFT FAN	20	11	11	11
3.3	PULVERIZER B1	150	70	65	68
	B2	150	78	73	76
3.4	CLASSIFIER	25	7	5	6
3.5	BOOSTER FAN	25	10	10	10
3.6	EXHAUST FAN	60	22	22	22

4.22 Flowrates

The Bauer mills, like the Raymond mill, consist of a grinding zone and classifying zone in one process unit. The Centri-Sonic classifier, located externally to the mills, normally produces only a small amount of rejects. Therefore, the pulverizing system was treated as open circuit. The flowrate of Product 903 was taken from plant records and, including both mills, was 0.9 t/h.

The production rate of talc from the flotation circuit was not specifically measured but it is known that the yield of the circuit is 50%, i.e., two tonnes of material from the Raymond mill are required to produce one tonne of floated product.

4.23 Size Distribution

Size distribution determination by sedigraph for the flotation and pulverizing circuits was carried out on the dried flotation product and the finished Product 903. The results are presented in Table 10. A comparison of the results of the flotation product with flotation feed reveals a greater proportion of smaller particles in the floated product. This may result from finer grinding of talc particles in the Raymond mill as compared to particles of impurities.

TABLE 10 - Pulverizing Particle Size Distribution

Size (μm)	% Passing		
	Feed	Flotation Product	Product 903
100	98.5	100.0	
70	93.0	97.5	100.0
50	79.5	88.0	99.5
40	70.5	79.0	99.5
30	57.5	67.5	99.0
25	52.0	61.0	99.0
20	43.0	51.0	99.0
15	33.0	40.0	98.0
10	20.0	23.0	94.0
8	15.0	16.5	89.0
6	10.5	10.5	69.0
4	6.5	6.0	14.5
2	2.0	1.5	5.0

The results of the sedigraph on the finished product demonstrate the extreme fineness to which the talc is eventually ground. The narrow range of size distribution is also evident by the steepness of the graph, Figure IV.

4.24 Specific Energy Consumption

Energy consumption is reported for pulverization only. This data is contained in Table 11.

TABLE 11 - Pulverizing Power Consumption

	kWh/tonne	
	Specific	%
Grinding Only	158.9	73.6
Auxiliaries	57.1	26.4
Total	216.0	100.0

This data reveals the very high energy consumption required to make the product 903 compared to the dry-milled products.

4.25 Comminution Power Consumption by Product

The comminution power requirements per tonne of product are summarized in Table 12.

TABLE 12 - Power Consumption

Department	Product Al		Product 903	
	kWh/t	%	kWh/t	%
Crushing	1	2.4	2	0.8
Grinding				
Raymond Mill	40	97.6	30	12.1
Pulverizer	0		216	87.1
Total	41.0	100.0	248	100
Flowrate (t/h)	2.3		0.9	

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION **BT SUPER HI-TALC 903 (83054)**

DATE **June 14, 1983**

Density **3.12** g/cc LIQUID **A-13** Density **0.820** g/cc Viscosity **8.064** cp

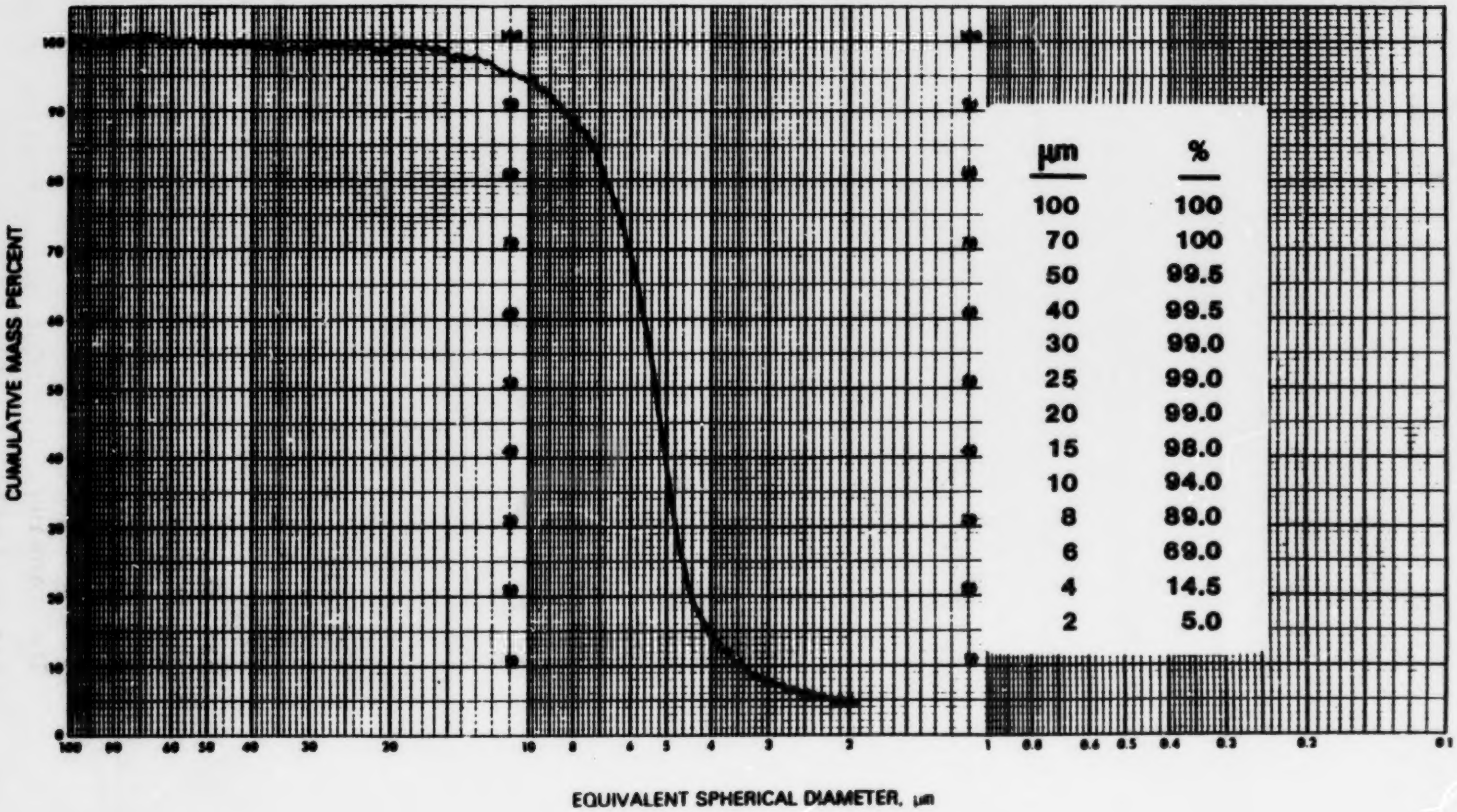
BY **R. Ferguson**

Preparation

TEMPERATURE **32** °C

Figure IV

RATE **242** START DIA **100** µm



µm	%
100	100
70	100
50	99.5
40	99.5
30	99.0
25	99.0
20	99.0
15	98.0
10	94.0
8	89.0
6	69.0
4	14.5
2	5.0

micromeritics
instrument corporation

Form 500/42701

Power demand for product 903 is six times greater than that of product A1, mainly due to the pulverizer which is required to give 903 a suitable degree of fineness.

It should be noted that the crushing power for 903 is double that of A1 because fifty percent of the crushed material is lost to benefication during production of 903.

4.26 Chemical Composition and Brightness

The most noticeable changes are in the silica content, which has gone from 37% to 57% (63% is the SiO_2 portion of pure talc) and the loss on ignition which has dropped from 20% to 8%.

TABLE 13 - Chemical Composition

	Flotation Feed %	Flotation Product %
SiO_2	37.24	56.86
$Al_2O_3 + TiO_2 + P_2O5$	2.94	1.53
Fe_2O_3	6.48	3.89
CaO	2.22	0.29
MgO	29.83	29.54
Na_2O	0.00	0.00
K_2O	0.03	0.00
SO_3	0.31	0.09
L.O.I. (1050°C)	20.45	7.83

Brightness testing was done on the flotation feed and product as well as the three finished products. The results indicate that both fineness and purity of the talc play a role in brightness and both factors are strongly present in product 903 to give this material its desired characteristics. The progressive increase in material brightness can be seen as the talc passes through the process and becomes increasingly refined.

The ranking, in order of increasing brightness, is: flotation feed, A1, flotation product, A_3, and 903.

5. CONCLUSIONS AND RECOMMENDATIONS

The results generated by this study provide a good "snapshot" at electrical energy consumption by Bakertalc Inc. in the area of crushing and grinding. The progression of consumption can be seen as the refinement of the talc proceeds through the stages of production. Relatively little energy is consumed in the screening and crushing with higher consumption for the various dry-milled products. Product 903 is by far the highest per tonne consumer of power because of additional processing and fineness of that particular product.

An important point noted with regard to the crushing circuit was that, while it is intended that the circuit product be minus 19 mm, sieve analysis of this sample showed that only 75% of the material met the requirement. Thus, more grinding work was passed on to the Raymond mill. Plant operators indicated, however, that some coarse material may improve mill operation since fine, relatively soft talc particles tend to coat grinding surfaces.

Raymond mill products were observed to be on target with regard to 45 μm fineness. The wear rate on this mill is evidently low since servicing or replacement of grinding surfaces has been minimal over the life of the mill. This is accounted for by the relative softness of the ore.

It is expected that iron content should decrease significantly through flotation since the ferruginous magnesite impurity has been removed. However, the reported Fe_2O_3 content of 3.89 seems relatively high. This suggests flotation efficiency may be improved by process tuning adjustments. Improved efficiency of the flotation circuit would decrease the impurities remaining in the floated product which would in turn contribute to increased brightness of the final product 903. Flotation productivity could also be increased.

Power measurements indicate that the Bauer mill motors were operating at a power level somewhat below their ratings. While a 150 HP motor would be expected to draw near 100 kilowatts of power, the motors were measured at about 70 kilowatts. The cause of this was not clearly diagnosed during the study.

Despite these few areas where the comminution circuit may have been operating below full efficiency, the comminution data collected at Bakertalc is probably representative of the industry.

In perspective, based on information from this study and plant operating records, the proportion of total manufacturing cost attributable to electric energy consumption by comminution and auxiliaries is not large. While this consumption is nearly half the electrical consumption, electrical costs represent only about 10% of manufacturing cost. Thus, the effect on manufacturing cost of improvements to comminution processes would be small.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

In Canada, talc is mined in Quebec and Ontario. Areas of production in the United States are Vermont, New York, Texas, Montana and California.

North American output is summarized in Table 1.

TABLE 1 - Talc & Pyrophyllite: North American Production[6]

COUNTRY	(000' tonnes)					
	1977	1978	1979	1980^p	1981^e	1982^e
Canada	72	62	90	92	83	72
United States	1,093	1,255	1,318	1,125	1,218	1,030
Mexico	-	3	3	2	3	-

p - Preliminary e - Estimated
Sources: Minerals Yearbook Centennial Edition 1981
Mineral Commodity Summaries, 1982; EMR Canada

Talc, as a pure mineral, has a composition of 63.36% SiO_2, 31.89% MgO and 4.75% H_2O.[5] In practice, commercial talc rarely approaches this purity.

It is common to group talc, soapstone and pyrophyllite together. The chemical nomenclature and formulae for talc and pyrophyllite are:

Talc:	Hydrous magnesium silicate $Mg_6 [Si_8O_{20}] (OH)_x$
Pyrophyllite:	Hydrous aluminum silicate $Al_4 [Si_8O_{20}] (OH)_x$

Soapstone is used mainly in carving art and pyrophyllite for uses similar to talc.

Talc was formed by metamorphic or hydrothermal alteration of rocks rich in magnesia, mostly ultrabasic igneous rocks and sedimentary dolomite. Pyrophyllite was formed by hydrothermal alteration of acid igneous rocks.

Talc ores are generally beneficiated with relative ease and the by-products of a talc processing plant often have commercial value. Despite the relatively low purity of most ores, talc has a steadily increasing number of uses in cosmetics, ceramics, paper, plastics and rubber. It is subject to increasing demand for high purity and quality control. For example, until 1960, talc and talcose products were accepted by the cosmetics industry, based on rather loose and uncomplicated specifications. Cosmetic talc had to be reasonably light colored, have good "slip, be free of "gritty" or hard mineral particles and meet a certain fragance retention standard. The cosmetic industry has now set higher standards and new rulings from Federal agencies have made heavy demands on talc product quality. Typical talc quality criteria for specific uses are shown in Table 2.

TABLE 2 - Talc Characteristics for Specific Uses[5]

USE	CHARACTERISTIC
Paint	Colour (whiteness) Particle shape Packing quality Oil absorption Fine particle size Opacity
Paper	Free of grit Colour Opacity Particle size Low alkali content
Ceramics	Uniform chemical composition Constant shrinkage on firing Fired colour Particle size distribution

Talc mining operations are generally on a small scale of less than 270 tonnes per day with equipment that is usually unsophisticated and capable of producing only a few tonnes per hour. Talc mining needs good housekeeping because of purity requirements. Underground crushing may be done before the ore is transferred to the grinding plant.

Talc milling has traditionally involved dry-processing operations, although it is evolving from simple grinding plants to sophisticated processing operations. Talc processing plants now include flotation, sedimentation, hydrocycloning, dry and wet magnetic centrifugal sizing, spray drying and new grinding techniques. Talc is commonly ground using ceramic grinding media. Some specialized grinding equipment is required for processing talc for specific markets. Talc sold as paper filler generally meets an average particle size of less than 5 µm and may sometimes be less than 1 µm. This requirement is met with vertical shaft pulverizing mills and jet-milling equipment.

In large talc plants (+100,000 tpy), sophisticated laboratory procedures have been introduced to control product quality. Some plants have facilities for chemical and instrumental analysis, surface area determination, color, oil absorption, particle size and shape determination, packing quality and others.

Canadian Industry

The earliest recorded activity involving talc, soapstone and pyrophyllite in Canada was in the 1870's with a shipment of soapstone from a deposit in Quebec.1 In 1896, a deposit in the Madoc district of Ontario was opened and mined intermittently over the next few years. Deposits in southern British Columbia and southwestern Alberta were discovered prior to 1920 and produced small amounts.

Current Canadian talc, soapstone and pyrophyllite production, with a breakdown of production value by province and imports are shown in Table 3.

At present, talc is mined by four companies in Canada, two in Quebec and two in Ontario.

Bakertalc Inc. produces talc from an underground mine in Quebec, southeast of Montreal. Ore from the mine is processed at the company's mill facilities at Highwater. Ore hoisting at the mine is by way of a 45° inclined shaft. High quality talc for use in the paper industry is produced by a modified flotation process. Some product has been used as a filler in plastics and paints. The company also produces a lower grade talc in a dry-milling process.

Capacity: 3,000 tpa dry-milled and 5,000 tpa flotation product.

B.S.Q. Talc Inc. (formerly Broughton Soapstone and Quarry) quarries talc from deposits in the Eastern Townships in Quebec, where several low-priced grades of ground talc are produced. Most is used in roofing materials or as a rubber filler.[3]

Capacity: 22,000 tpa.

Canada Talc Industries Limited produces talc from an underground mine at Madoc, Ontario.[1] A high quality product is produced for use as a filler in paint and plastics and for use in pharmaceuticals, cosmetics and lens polishing. The company is adding some micrometer grades and a 200 mesh ceramic grade to its product line. The mill circuit contains a jaw crusher, Raymond mills, pebble mills and classifiers.

Capacity: 25,000 tpa.

Steetley Mineral Group, through a subsidiary Steetley Talc Limited, produces talc from a deposit at Penhorwood Township in Ontario. The talc is a high purity, platey material and is produced by flotation.[3] Although the biggest market is as a pitch control agent in pulp, other uses include fillers in paint and plastics as well as cosmetics. Steetley anticipates that the market in plastics, especially in heat resistant polypropylene, could be good in the future.

Capacity: 25,000 tpa.

TABLE 3 - TALC, SOAPSTONE AND PYROPHYLLITE PRODUCTION, 1978-82[1]
(in thousands of tonnes and dollars)

PRODUCTION (Shipments)	1978		1979		1980		1981		1982P	
	t	$	t	$	t	$	t	$	t	$
Talc and Soapstone										
Quebec*	-	1,072	-	1,500	-	1,400	-	1,356	-	1,475
Ontario**	-	440	-	914	-	1,437	-	2,102	-	3,429
Total	-	1,513	-	2,414	-	2,837	-	3,458	-	4,904
Pyrophyllite										
Newfoundland	-	664	-	1,025	-	1,040	-	1,003	-	552
Total Production	62	2,177	90	3,439	92	3,877	83	4,462	72	5,456
Total Imports	33		50		50		30		35	

Sources: Statistics Canada; Energy, Mines and Resources Canada.
* Ground talc, soapstone, blocks and crayons
** Ground Talc
P Preliminary
- Not Available

Market Outlook

Except for minor shipments to South Africa, talc exports are to the United States where there is a rapidly growing demand for good quality filler for automobile plastics.[1] Most talc imports are from the United States and are high quality, high value materials for use in the paint, ceramic, paper and cosmetic industries. It is expected that high quality talc imports will be replaced somewhat in other industries by domestic products, as capacity for producing higher grades increases.

It is anticipated that the talc market in the paper industry will grow both in pitch control and in filler and coating applications. In the cosmetic market, competition may be keen in a few years as more companies vie for position. Another factor that is threatening in the cosmetic market is that corn starch can replace talc in applications like baby powder.[3]

Minerals competing with talc are feldspar, wollastonite and nepheline syenite in ceramics, mica in the roofing market, and specially purified, calcined and compounded clays in paint, paper and plastics. Titanium dioxide is not as competitive as a filler due to high cost. The most important competitors in the filler market are limestone and dolomite fillers. Limestone is considered to be the most versatile mineral filler and its widespread availability and, therefore, low transportation costs will ensure it continues to be competitive. As talc products increase in purity and quality, more talc by-products will be produced with the possibility of a greater range of application.

The designation "industrial talc" includes earth minerals of widely different chemical and mineral compositions.[4] Single particles of talc have a range of water content from 3.5% to more than 7% and slight differences in MgO and SiO_2 proportions. The chemical composition of a typical, relatively high grade, industrial talc is shown in Table 4.

TABLE 4 - Chemical Analysis of Industrial Talc[4]

Oxide	Percent
SiO_2	62.65
Al_2O_3	0.31
Fe_2O_3	-
FeO	-
CaO	trace
MgO	30.23
$Na_2O + K_2O$	0.20
L.O.I.	4.95
H_2O	4.87
CO_2	0.27

Most industrial talcs are mixtures of silicates and contain significant amounts of magnesia. Other minerals commonly found in talc ores are serpentine, chlorites, tremolite and carbonates calcite, dolomite and magnesite.

Approximate compositions of these materials are shown in Table 5.

TABLE 5 - Approximate Composition of Minerals[4]

Mineral (Weight %)	CaO	MgO	Al_2O_3	SiO_2	CO_2	H_2O
Serpentine		43		44		8-13
Chlorite		36	18	33		5-14
Tremolite	13	28		57		1.5-2.3
Calcite	56				44	
Dolomite	30	22			48	
Magnesite		48			52	

If some of these minerals, along with sulfides, sulfates, and iron and manganese oxides, are present in more than trace amounts, the use of a talc may be restricted or its value lowered. Occasionally, some minerals may give a chemical composition and other properties to the product which are highly desirable for a specific use. For example, a talc high in the mineral tremolite may be ideally suited for use in some paints and certain ceramics.

Because of its platey nature, talc increases the tensile and impact strength of filled polymers. Pure talc is relatively inert and remains undecomposed in acid. When heated, part of the water that is commonly present can be driven off with no change in optical or crystalline properties. Industrial talcs are produced from rocks with a wide range of grain size; the talc component and other minerals may be foliated, granular or fibrous. The fibrous and foliated forms are related to cleavage and partings of the minerals and, therefore, remain after the finest grinding.

Particle-size specifications for most uses require the talc to be minus 45 µm. The specification for paint is 99.8 to 100 percent minus 45 µm; while for rubber, ceramics, insecticides and enamels, 95 percent minus 45 µm is common. For wall tile, 90 percent minus 45 µm is required and roofing grades require minus 180 µm, with a maximum of 30 to 40 percent minus 75 µm.[3]

For the paper industry, talc must be free of chemically active compounds like carbonates, iron and manganese, possess a high reflectance and be free of abrasive impurities. For ceramics, talc must be low in iron, manganese and other impurities that would cause discoloration on firing. In the paint industry, specifications for talc pigment relate to chemical composition, color, particle size and oil absorption. A low carbonate content, nearly white color and controlled particle size distribution are also important. Nevertheless, because of the wide variety of paints, precise specifications for talc pigments are commonly based on agreement between supplier and consumer.

For use in pharmaceuticals and cosmetics, talc should be free of abrasive impurities and fibrous minerals which could be harmful when inhaled or ingested. Many applications, such as dusting agent for asphalt roofing and gypsum board, filler in drywall sealing compounds and auto-body patching compounds, use lower grade talcs and, therefore, the specifications for these uses are less strict.

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REFERENCES

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PHASE II

Establishment of Particle Size Monitoring Methodology

INTRODUCTION

Most of the information in this report has already been given in the summary volume. In fact, the only significant differences are the inclusion of additional particle size analyses of a number of cements and a note on the precision of the Blaine air permeability test procedure.

REQUIREMENTS (as defined by CANMET)

Establishment of Monitoring Methodology

"A laboratory evaluation of commercially available and experimental instruments and monitoring techniques and systems potentially applicable to real-time monitoring of fine particles in grinding circuits shall be made and either existing equipment shall be selected or modified or new equipment shall be developed for subsequent pilot plant studies or real-time circuit control. It shall also be required to develop a sound sampling strategy and ensure good execution."

The preparation of a detailed technical proposal and cost breakdown for the Phase III work is to be provided as part of this requirement. A preliminary description of the third phase is included below.

Development of Pilot Plant Systems (Description Only)

"A pilot closed circuit grinding system would be set up reflecting the best available state-of-the-art technology with respect to the needs of representative industrial minerals comminution. The plant would be instrumented for direct energy measurements and designed to allow modular introduction of experimental control systems and removal of material at various stages of comminution. Selected mineral products would be ground in the circuit with a record of total energy audit versus operating characteristics being established for each.

Monitoring/control systems to optimize the total energy consumption would be developed along with necessary software and hardware for their ultimate introduction into full scale plants. In essence, the pilot plant would become a "test-bed" for evaluating grinding control systems and procedures. Direct energy consumption would be immediately measured by instrumentation, indirect energy consumption would be measured or estimated off-line in parallel experiments related directly to the needs of the product user."

MONITORING METHODOLOGY

Introduction

The advantages of on-line control of milling circuits has been pointed out in a number of articles[1-4]. This interest in automatic control has given rise to development of a range of different types of equipment for on-line particle size measurement.

Davies[1] has identified 21 classes of equipment, classed on the basis of the principles used to sense and size the particles. This article, and earlier reviews[5] by the same author, describe the equipment in some detail.

Principles used to sense and size particles

1. Image replication and analysis
2. Electrical resistance change
3. Light scattering
4. Light obscuration
5. Light diffraction
6. Optical grating method
7. Beta-ray attentuation
8. X-ray absorption and fluorescence
9. Acoustic interference
10. Ultrasonic attenuation
11. Differential air classification
12. Hydroclone separation
13. Pulsating gas flow
14. Pressure drop in a nozzle
15. Transient and evaporative cooling of a hot wire
16. Impact and momentum measurement
17. Magnetic flux variations
18. Electrostatic ion capture
19. Glow discharge perturbation
20. Automatic sieve methods
21. Correlation techniques

Most of the instruments listed are either not directly applicable to the industrial mineral sector or not sufficiently proven to be regarded as commercially available. Thus, in order to focus the study, we investigated the status of on-line equipment development in North America and Europe. From this investigation, it was decided to direct attention to equipment based on light scattering and diffraction.

In addition, it was decided to study the status of automatic Blaine meters, which give a measurement of specific surface area rather than particle size, but could be used in control of mill circuits, particularly in cement plants.

As representative of light scattering equipment, the Microtrac, marketed by the Leeds and Northrup Company, was chosen because of its degree of development and commercialization in North America.

The Microtrac was evaluated under laboratory conditions. Its accuracy and repeatability were compared to the Sedigraph,* an instrument whose operating characteristics have been established over a long period.

No laboratory evaluation was made of automatic sampling equipment because a range of different types of samplers are commercially available and have been proven under plant conditions.

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* The Sedigraph 5000 is manufactured by Micromeritics Inc., Norcross, Georgia. It employs the sedimentation principle, with particles settling in a proprietary liquid and a beam of x-rays as detector.

Laboratory Comparison of Laser and Sedimentation Particle Size Analysis

The comparison of the two types of instruments was based on cement samples of which the 45 µm size had been determined by wet sieving, and other materials from the comminution study. The 45 µm size has been used as a quality parameter in the cement industry for many years. It has been accurately defined by the industry and by the U.S. National Bureau of Standards using electroformed micromesh sieves and, therefore, is a good reference point for establishing the accuracy of the Microtrac and Sedigraph.

The Microtrac can be used for wet or dry samples but, because of difficulties experienced in getting the dry sampling system to operate satisfactorily and concern about agglomeration of particles in the air stream, the comparison between the two instruments was carried out on slurried samples. Water, with a small quantity of detergent, was used as the dispersing medium for Microtrac samples. A proprietary liquid, Sedisperse A13, was used with the Sedigraph.

Sedigraph

Repeatability

To evaluate the repeatability of the Sedigraph, tests were made on a Portland cement from C.E.R.I.L.H.*, the research centre of the French cement industry.

Results obtained with the French cement are shown in the table overleaf. The particle sizes in the table are chosen to coincide with those detected by the Microtrac.

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* Centre d'Études & de Recherches de l'Industrie des Liants Hydrauliques.

Sedigraph - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	96.5	98.0	97.0	97.0	97.0	98.5	97.3	0.60	2.0
62	93.0	94.0	93.5	91.5	91.0	94.0	92.8	1.07	3.0
44	85.5	85.0	85.5	83.0	81.5	85.5	84.3	1.40	4.0
31	71.5	71.5	71.5	70.5	69.0	73.5	71.3	0.98	4.5
22	60.0	57.0	57.5	56.5	55.5	60.0	57.7	1.43	4.5
16	45.5	44.5	45.0	45.0	44.5	47.0	45.3	0.68	2.5
11	33.5	33.0	33.0	33.5	33.0	36.0	33.7	0.80	3.0
7.8	24.5	23.5	24.0	24.5	24.5	26.5	24.6	0.65	3.0
5.5	17.5	16.5	17.0	18.0	18.0	19.5	17.8	0.75	3.0
3.9	12.5	11.5	11.5	13.0	13.5	14.5	12.8	0.92	3.0
2.8	8.5	7.5	7.0	9.0	9.5	10.0	8.6	0.92	3.0

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The accuracy of the Sedigraph was determined from results obtained on a C.E.R.I.L.H. cement which is used as a standard for particle size analysis.

The results are given below.

Sedigraph - C.E.R.I.L.H. Cement

Cumulative % finer than size shown.

µm	Mean Sedigraph Value (%)	Assigned Value (%)
88	97.3	94.5
62	92.8	89.5
44	84.3	82.0
31	71.3	70.0
22	57.7	57.0
16	45.3	44.5
11	33.7	35.0
7.8	24.6	25.5
5.5	17.8	20.0
3.9	12.8	14.0
2.8	8.6	9.5

A further evaluation of Sedigraph accuracy was made from the 45 µm (#325 mesh fineness) determination on the six Portland cements. The #325 mesh fineness had been determined by wet sieving at ten separate laboratories as part of a Canada Cement Lafarge inter-laboratory program. Sedigraph and #325 mesh results are compared in the following table.

Wet Sieving v. Sedigraph at 45µm

Sample No.	#325 (45µm) % Passing	Sedigraph % finer than 45µm
240	94.3	95.2
241	98.1	98.0
277	94.9	94.1
281	86.3	85.8
287	91.1	90.0
294	95.3	95.1

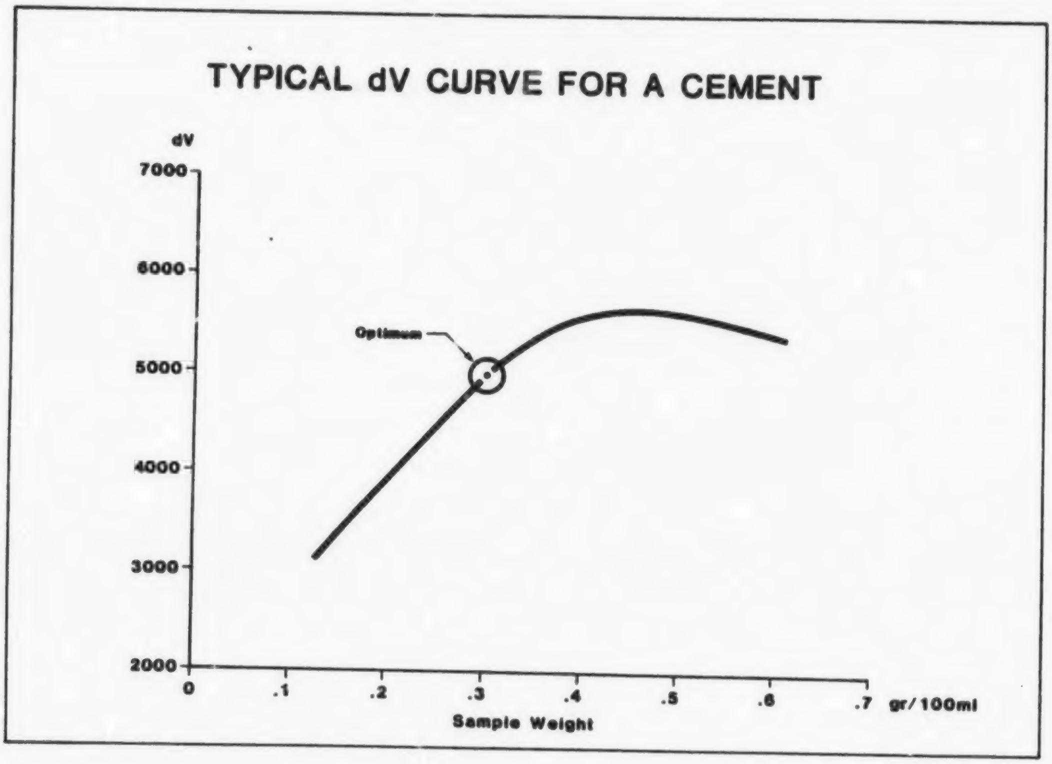
It is concluded from the results that, over the particle size range under study, the Sedigraph has both good accuracy and repeatability.

Microtrac

The Microtrac results are influenced by the weight of sample (as opposed to the Sedigraph which is relatively insensitive to sample weight). The manufacturer stresses the importance of the optimum weight of sample, and the instrument is equipped to indicate this optimum in the form of a number called "dV".

The dV number is defined as "a volume response giving an uncalibrated indication of the amount of particulate matter in the system". With the Microtrac, it is important that sample loading be low enough to keep main-beam attenuation and multiple light scattering at non-critical levels but high enough to achieve good resolution at the diffraction angles involved.

Optimum sample loading is obtained by plotting the dV number against variations in sample weight. The recommended sample weight is that near the peak of the resulting curve. A typical dV curve is shown in the figure below.



Results of dV and optimum loading weights for the six test Portland cements are given below. Densities for Portland cements are constant at 3.15 g/cm3.

Optimum Loading and dV for Portland Cements

Sample No.	Surface Area Blaine (cm^2/g)	dV	Optimum Sample Weight (g)
240	5490	.2396	0.15
241	5290	.2483	0.15
277	4500	.4006	0.25
281	2980	.5645	0.30
287	3420	.4518	0.30
294	4010	.3794	0.25

The results indicate that dV and optimum loading weights vary in relation to the surface area of the material in spite of a constant density.

Optimizing the dV response of the Microtrac will be an important parameter in any on-line application where wide ranges of fineness could be found.

Repeatability

Repeatability of the Microtrac for the analysis of a standard cement is demonstrated in the next table, which shows that the variation in Microtrac results is similar to the Sedigraph for the standard cement.

Microtrac - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	100	100	100	100	100	100	100	0.00	0.0
62	98.1	100	99.4	100	99.8	100	99.6	0.52	1.9
44	94.7	98.1	95.8	96.5	96.2	96.7	96.3	0.77	3.4
31	85.7	87.1	87.5	86.1	87.0	85.8	86.5	0.67	1.8
22	71.1	71.0	73.4	72.6	72.0	73.0	72.2	0.82	2.4
16	57.0	58.9	59.1	58.4	58.0	58.3	58.3	0.52	2.1
11	41.2	42.6	42.1	42.2	42.6	42.0	42.1	0.35	1.4
7.8	28.5	29.1	29.9	29.3	28.0	29.5	29.1	0.52	1.9
5.5	17.1	18.4	20.4	18.7	17.6	19.3	18.6	0.88	3.3
3.9	8.6	9.5	10.5	9.8	9.3	10.4	9.7	0.55	1.9
2.8	4.4	4.7	4.4	4.1	4.3	3.9	4.3	0.20	0.8

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The Microtrac results for the standard C.E.R.I.L.H. cement are compared with the assigned values in the following table.

Microtrac - C.E.R.I.L.H. Standard

Cumulative % finer than size shown.

Particle Size (µm)	Mean Microtrac Value (%)	Assigned Value (%)
88	100	94.5
62	99.6	89.5
44	96.3	82.0
31	86.5	70.0
22	72.2	57.0
16	58.3	44.5
11	42.1	35.0
7.8	29.1	25.5
5.5	18.6	20.0
3.9	9.7	14.0
2.8	4.3	9.5

The Microtrac results are considerably higher than the assigned values from 88 to 7.8 µm. Below this particle size, the results are lower than assigned values.

An estimation of Microtrac accuracy was also made by evaluating its performance at the 45 µm size. The following table, comparing wet sieving, Sedigraph and Microtrac results for the six test cements, confirms that the Sedigraph is more accurate for this particle size.

Wet Sieving v. Microtrac at 45 µm

Sample No.	No. 325 (45 µm) % Passing	Microtrac % Finer Than 45 µm
240	94.3	100.0
241	98.1	98.8
277	94.9	97.0
281	86.3	87.5
287	91.1	97.2
294	95.3	94.8

On the average, Microtrac results are consistently higher than those of wet sieving, but not to the extent seen with the standard cement.

The fact that the Microtrac gives somewhat higher readings than the Sedigraph is confirmed by the results of the tests on four Type 10 and two Type 30 cements.

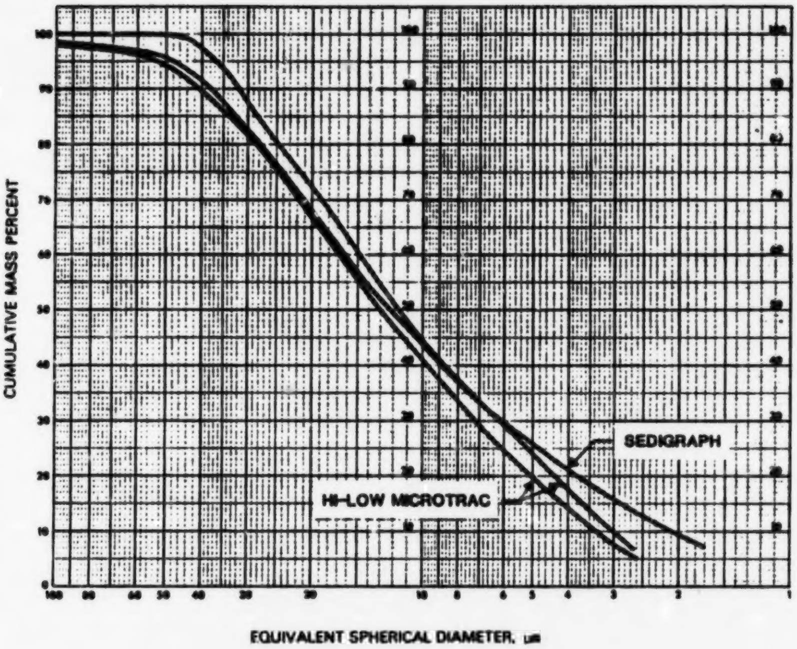
The Blaine and % passing 325 mesh are as follows:

	Sample Code	Blaine M^2/kg	% Passing 325 mesh
Type 10			
	Interlab 277 R	450	94.9
	Interlab 281	300	86.3
	Interlab 287	343	91.3
	Interlab 294	401	95.3
Type 30			
	Interlab 240	524	94.3
	Interlab 241	529	98.1

The results from the two instruments are shown graphically on the following pages.

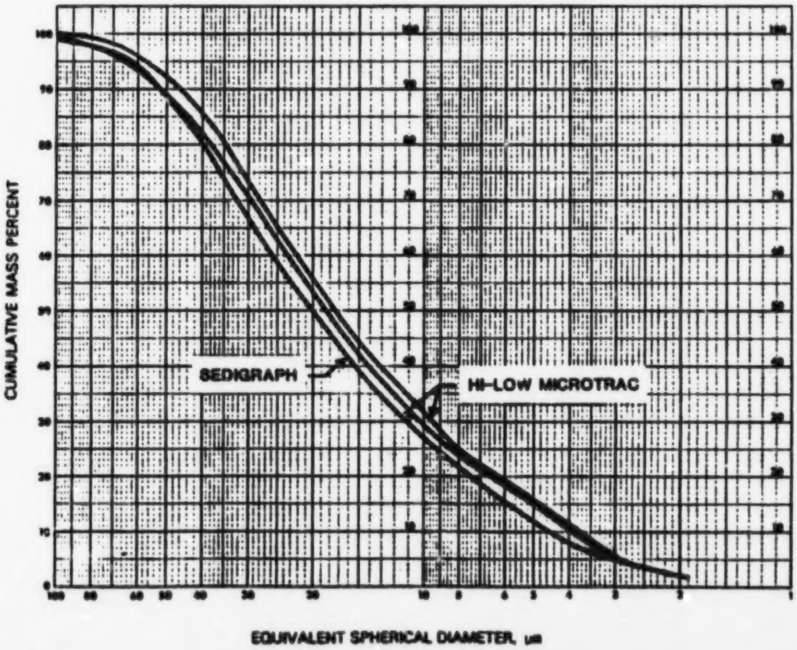
INTERLAB 277 R

% Passing 325 = 94.9 Blaine 450 M^2/kg



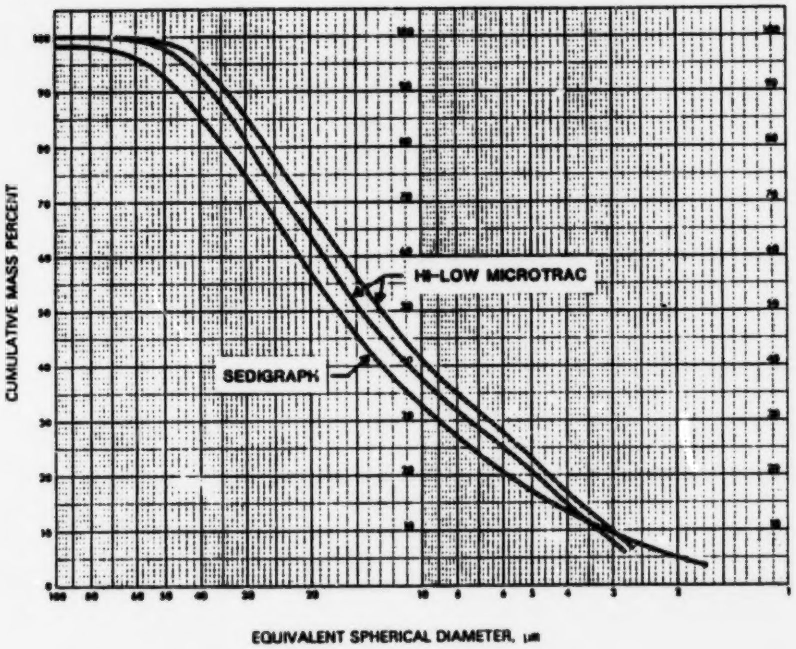
INTERLAB 281

% Passing 325 = 86.3 Blaine 300 M^2/kg



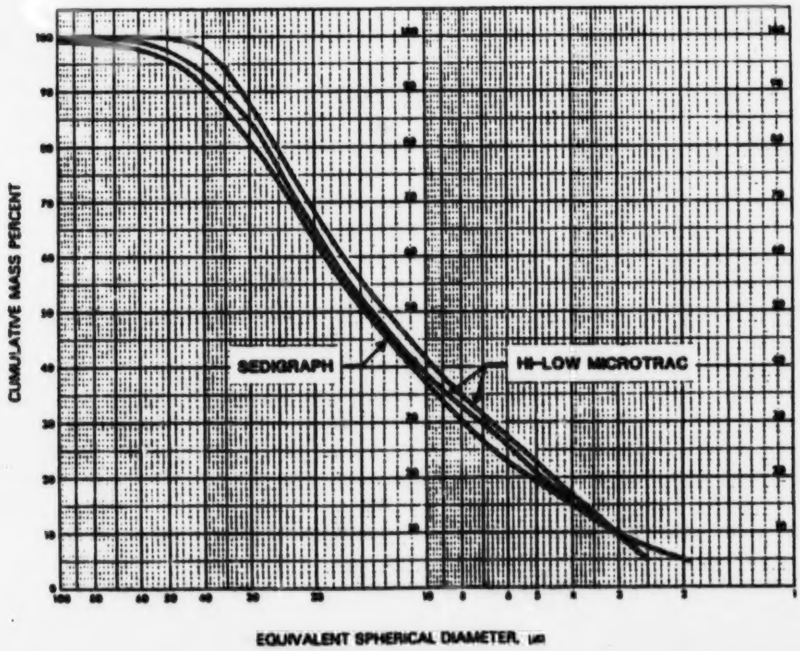
INTERLAB 287

% Passing 325 = 91.3 Blaine 343 M^2/kg



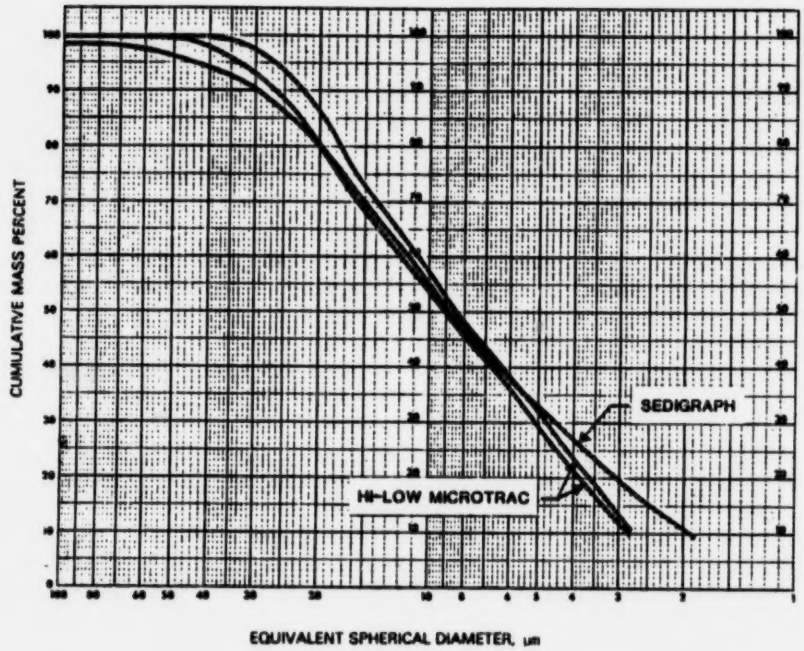
INTERLAB 294

% Passing 325 = 95.3 Blaine 401 M^2/kg



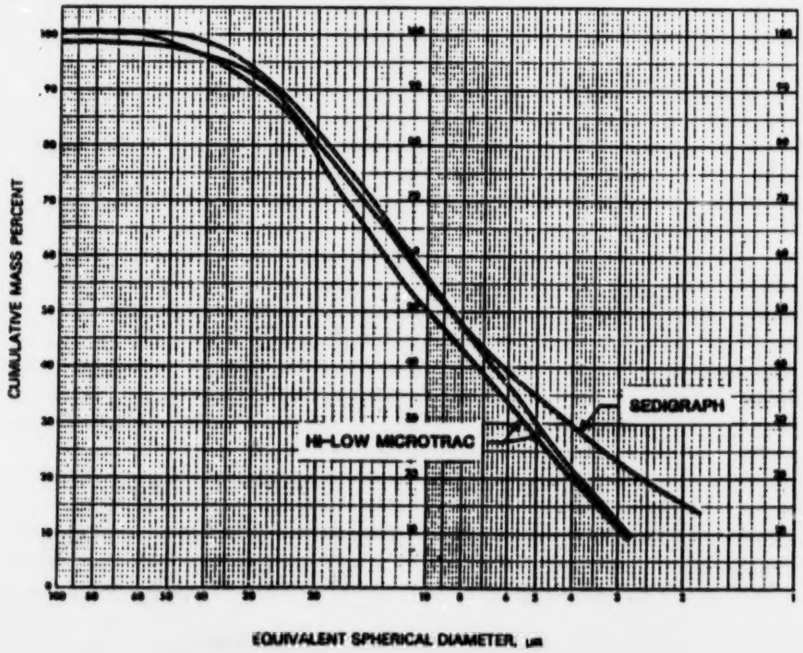
INTERLAB 240

% Passing 325 = 94.3 Blaine 5240 M^2/kg



INTERLAB 241

% Passing 325 = 98.1 Blaine 5290 M^2/kg

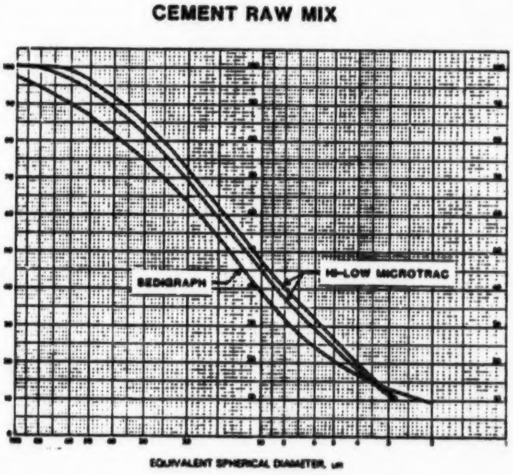


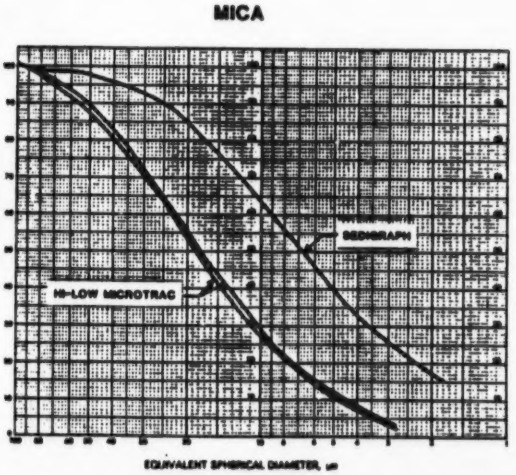
Particle size analysis of non-cement materials

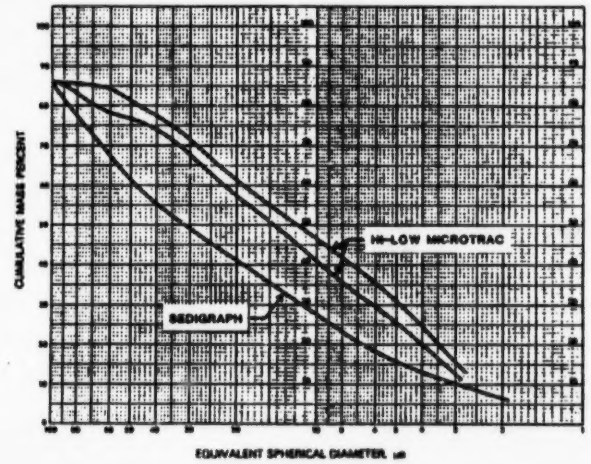
A comparison of the results from the Microtrac and Sedigraph analysis of the following materials

- cement raw mix
- mica
- limestone, limestone (calcite)
- talc
- nepheline syenite

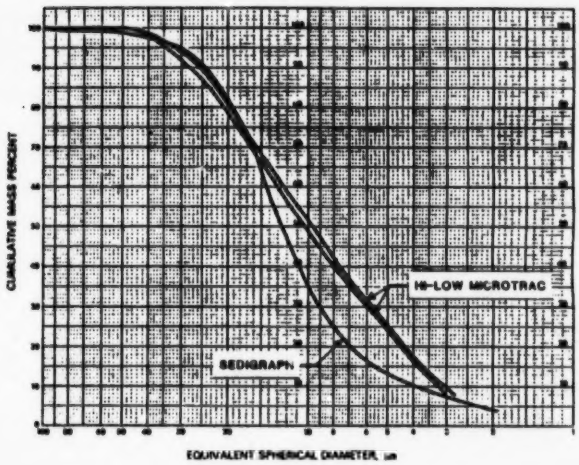
are shown in the graphs below. The "hi-low" Microtrac curves give the range of results obtained from a set of samples.


CEMENT RAW MIX

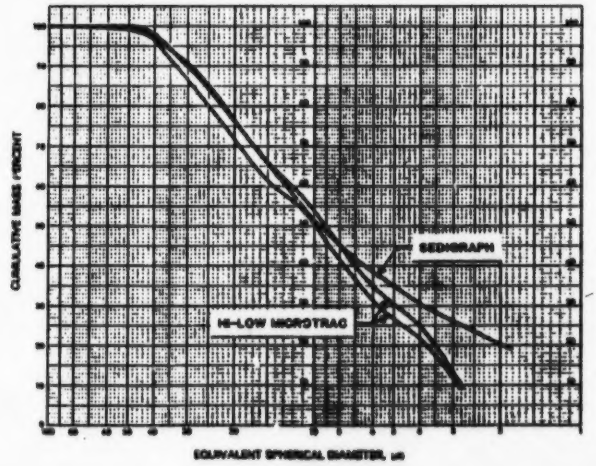

MICA



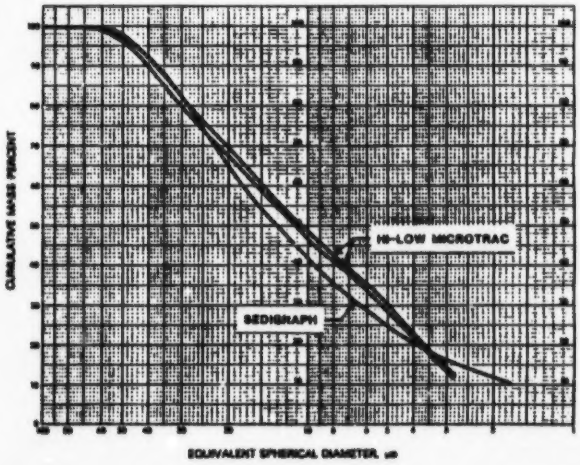
LIMESTONE



TALC



LIMESTONE - (Calcite)



NEPHELINE SYENITE

For the Portland cement raw mix, composed of a mixture of limestone and shale, No. 325 wet sieving indicated 81.2% passing at 45 µm. The Sedigraph and Microtrac gave 83.8% and 93.0%, respectively. This result is consistent with earlier data indicating that the latter is less accurate at the coarse end of the scale.

The results for the mica sample show the largest difference between the two instruments. The wide difference in results could be attributed to the shape of the particles affecting sedimentation.

There is also considerable difference in results for the Domtar limestone sample. Differences like this are difficult to explain without further exploration, but could be due to poor dispersion in water of the Microtrac samples.

In general, the reproducibility of the Microtrac results for the industrial minerals was found to be within the ±5% range quoted by Leeds and Northrup[9].

On-line Application of Particle Size Analysers

On-line applications of a number of types of particle size analysers are summarized in the table below.

ON-LINE APPLICATIONS			
CLASSIFICATION BASED ON PARTICULATES CONCENTRATION IN THE SENSING REGION	MODE		CURRENT STATUS
	WET	DRY	
I. Low Concentration Methods (single particles)			
- Electrical Conductivity	X		- Restricted to contaminants.
II. High Concentration Methods (5-70% by weight)			
- Hydrocyclone	X		- Tested in plant environment[6].
- Automatic Sieving	X		- Not in current use. Min. 100 μm particles.
- Ultrasonic Attentuation	X		- Tested in plant environment[6] (Armco Autometrics).
- Beta-Ray Attentuation	X		- Not in use.
III. Intermediate Concentration Methods (0.1% by weight)			
- Light Diffraction		X	- Cilas; not in current use.
	X	X	- Microtrac: currently installed in a number of locations.
- Differential Air Flow		X	- Metzger & Leschonski's Model: commercialization in process[8].
IV. Air Permeability (Blaine meter)		X	- Japanese development - unknown; presumed abandoned
		X	- Fuller's mid 70's model: abandoned.
		X	- Milltronic's early 70's model: abandoned.
		X	- HolderBank - Hasler: currently in plant testing.

The first category is applicable to low concentrations of particles and not directly relevant to industrial mill circuits. The high concentration methods were not explored further because they do not appear to be under active development at present.

Of the remaining two categories, laser systems have been tested under plant conditions, a differential air flow method is reported to be ready for commercialization and at least two automatic Blaine meters are installed in plants.

Laser Systems

The Microtrac is the most widely commercialized particle size analyser in this category. In North America, some 400 units are reported to have been sold to a wide range of industries, including explosives, food, chemicals, minerals and oil.

A number of industries, where on-line monitors are installed, were contacted. The applications are shown in the table.

ON-LINE MICROTRAC APPLICATIONS

INDUSTRIES	PLANT & LOCATION	PARTICLE CHARACTERISTICS	MODE	
			WET	DRY
Cement	- Calavares Cement Redding, California, USA	80-90% passing 325 mesh		X
	- Florida Mining Brooksville, Florida, USA			X
	- Lonestar Cement Seattle, Washington, USA			X
	- Blue Circle Industries Greenhithe, Kent, UK			X
Talc	- Talc-de-Luzenac Luzenac - Arièges, France	10-50 µm		X
Minerals (Tailings)	- Lornex Mining Logan Lake, B.C., Canada	2.7-300 µm	X	
Alumina	- Alcoa Tech. Centre Alcoa Centre, Pa, USA	--	-	-
Iron Ore	- Iron Ore Company Newfoundland, Canada	65% passing 44 mesh	X	
	- Bethlehem Steel Bethlehem, Pa, USA	--	X	

The results from the talc and iron ore plants were reported to be satisfactory, while the cement industry and mine tailings still had problems to overcome. The main difficulties cited for the dry mode were control and presentation of the sample in a dispersed form to the laser beam. In the wet mode, daily clean-up of the sample cell was necessary and abrasion was a problem. Very little quantitative data describing the performance of the instruments was available.

In general, some concern was expressed about the ability of the instrument to stand up to the heat, dust and vibration in a plant environment.

Permeability Systems (Blaine meter)

Hasler Frères SA have developed an automatic Blaine meter. One of these meters has been installed at a German cement plant since 1982 and is, according to a Hasler report[10], operating well.

The objectives of the installation were;

1) to insure a constant fineness of the finished cement within a divergence of ± 100 for three different Blaines (3100 - 4300 - 4900 cm^2/g);
2) to have maximum possible output at these finenesses;
3) to reduce the energy consumption of the mill to the minimum;
4) to be adjusted easily to different types of input material;
5) to enable the system to be controlled remotely.

The mill being controlled has two compartments, a 3500 hp motor and an output of about 100 t/h. It is equipped with a Pfeiffer Turbo separator.

Ciments Lafarge France commissioned a Hasler automatic Blaine meter, at a cement plant in Marseilles, in early 1983. No reports on the performance of the equipment are available yet.

CONCLUSIONS

The Sedigraph is an accurate instrument, giving good reproducibility of results in the 100 - 2 µm range. Because of the time required to prepare and run samples, it is best suited for a laboratory role. However, it provides a useful reference for evaluating the performance of other instruments.

Laser based instruments of which the Microtrac is the most developed and commercialized in North America, could be used for on-line particle size analysis in the industrial minerals industry, if the problems associated with dispersing the particles and presenting a dry sample of suitable concentration to the sensor can be overcome.

The reproducibility of the Microtrac results is similar to the Sedigraph, but generally gives higher readings.

It can span a wider range of particle sizes, 200 - 2 µm, compared to 100 - 2 µm for the Sedigraph.

The Microtrac scanning time can be as low as 25 seconds, compared to 25 minutes for the Sedigraph.

The Microtrac has apparently been tried in a number of on-line applications but with limited success.

Automatic Blaine meters are installed in at least two cement plants in Europe. One is reported to have performed satisfactorily since 1982. The other was commissioned in 1984.

The Blaine meter gives a measure of specific surface area rather than particle size and has a slower response time than the Microtrac but could be used for mill circuit control, particularly in the cement industry.

APPENDIX

The precision of the Blaine air permeability test.

PRECISION

Blaine Air Permeability Determination

ASTM has found the precision for the Blaine Air Permeability C 204 Test Method to be:

Single Operator

One Sigma Coefficient of Variation (1S%)	1.2%
Difference Two Sigma Coefficient of Variation (D2S%)	3.4%

Multilaboratory

One Sigma Coefficient of Variation (1S%)	2.1%
Difference Two Sigma Coefficient of Variation (D2S%)	6.0%

The One Sigma Coefficient of Variation is defined as:

the standard deviation expressed as a percent of the average of test results on a single sample.

The Difference Two Sigma Coefficient of Variation is defined as:

the difference between two individual test results, expressed as a percent of their average, that would be equaled or exceeded in only 1 case in 20.

The Difference Two Sigma Coefficient of Variation (D2S%) is calculated by multiplying 1S% by $2\sqrt{2} = 2.83$.

Canada Cement Lafarge Ltd., from its Interlaboratory Program has found the precision of the Blaine determination to be:

Multilaboratory

One Sigma Coefficient of Variation (1S%)	1.6%
Difference Two Sigma Coefficient of Variation (D2S%)	4.5%

These results were generated from Blaine determinations on approximately 40 Portland cements by 12 laboratories over an eight year period.

The improved Canada Cement Lafarge precision reflects the high degree of standardization among Company laboratories.

It is felt, however, that single operator precision for Canada Cement Lafarge would be at the same level as found by ASTM.

There is no general statement that can be made for accuracy. For multilaboratory results, accuracy and precision are almost synonomous. This may not be the case for single operator results.